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ABSTRACT

Following guidelines established in previous summaries of research, this review for the year 1974 portrays "the state of knowledge in science education, describes any existing trends, identifies areas which need to be researched, and provides tentative answers to persistent problems, if any seem to emerge from the research." Accordingly, research has been listed under those categories which seem most descriptive. General divisions appearing are: (1) learning; (2) education, characteristics and behaviors of teachers; (3) surveys; and (4) implications of the research reviewed. In all, 385 separate studies are cited in the bibliography, although considerably fewer are mentioned in the text. Through the use of the extensive index, however, the major thrusts of all reviewed research can be ascertained. (CP)

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SCIENCE EDUCATION INFORMATION REPORT

A SUMMARY OF RESEARCH IN SCIENCE EDUCATION - 1974

by
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FOREWORD

Research Reviews are being issued to analyze and synthesize research related to the teaching and learning of science completed during a one-year period of time. These reviews are developed in cooperation with the National Association for Research in Science Teaching. Appointed NARST committees work with staff of the ERIC Science, Mathematics, and Environmental Education Information Analysis Center to evaluate, review, analyze, and report research results. It is hoped that these reviews will provide research information for development personnel, ideas for future research, and an indication of trends in research in science education.

Your comments and suggestions for this series are invited.

Stanley L. Helgeson
and
Patricia E. Blosser
ERIC/SMEAC

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Introduction

A review of research is a hazardous undertaking. One would like it to be useful. But useful to whom and for what purpose? It should at least provide a list of studies completed during a specific period. We believe that the 385 entries in the bibliography represent a rather complete list of the research reported during 1974. By using this list together with bibliographies from previous reviews in this series, the reader should be able to locate studies of interest. But a bibliography does not constitute a review. What does one say about these studies? How can the comments be organized so that they will be of value? Which studies merit attention? These are the difficult questions.

Studies reported in any one year are likely to span many subjects and add merely drops to knowledge of a particular area. Without reference to what has gone before, it is difficult to assess the importance of this research. It would be nice to see each study reported in the context of prior effort. That is not easy to do. Given the breadth of the nearly 400 studies reviewed, no reviewer is likely to have the background needed to provide that perspective. Certainly, these reviewers do not! Still, as Rowe and DeTure pointed out in their 1973 review, a good review "should portray the state of knowledge in science education, describe any existing trends, identify areas which need to be researched, and provide tentative answers to persistent problems, if any seem to emerge from the research." These purposes are served only in so far as the reviewer is able to synthesize what is reviewed and to place it in the perspective of previous work. This we have tried to do but the reader will be aware of our limited success. We necessarily leave much to the reader. Each will bring his own knowledge to bear and impose his own organization. We can only share our limited insights and provide an organization that will not inhibit the reader's efforts.

Organization

In an attempt to help the reader abstract from this review that which he will find valuable, we have retained organizational elements from the 1973 review. We have, for example, included an index to assist the reader in finding studies of interest. The index contains entries in normal type which refer to the listing in the bibliography and bold type entries which reference the page of the review on which the study is discussed. This double notation has been used because a number of studies are not discussed

in the review. By indexing the bibliography as well as the review, the reader may be able to identify studies of interest that were not discussed.

Any attempt to organize studies into categories perfect for review is doomed to failure. Where does one discuss a study based on Piaget's theory of intellectual development which utilizes some method of individualized instruction in an attempt to evaluate a junior high curriculum project? Although no such study was reviewed, there were many which could logically fall into several categories. Choices had to be made. We tried to determine the main thrust of the investigation and categorize the study accordingly. But let the reader beware, studies of interest may appear in more than one section! In so far as possible, we have included parenthetical notes pointing to related studies which are discussed in other sections of the review.

The discussion above says nothing about what the categories of the review should be. Our decision was based on the assumption that this review would likely be used along with previous and subsequent reviews to find studies of similar purpose. If this is the case, it would be helpful if succeeding reviews used similar organizations and we decided to stick closely to the organization used by Rowe and DeTure in the 1973 review. It is one that might be useful over a number of years with only minor modification.

We have done one other thing which we hope will help the reader in the important task of synthesizing the research. We have repeatedly referred to studies reviewed in 1973 and have tried to show relationships when they were evident. We hope that this will enable the reader to leave the review with a greater sense of what we now know about a given area of research.

Selection of Studies

Many of the studies listed in the bibliography are not discussed in this review. In some instances the study was sound and clearly described but considered to be of such limited interest that it was not discussed. Many surveys fell into that category. More often, a study was not discussed because there was insufficient information in the abstract to tell what was done and what was learned. This is not a new problem. The 1973 review by Rowe and DeTure listed six questions that should be answered in order for an abstract to be of much value. These questions are worth repeating.

1. What are the independent variables?

2. What are the dependent or outcome variables?

3. How are the variables measured?

4. Who are the subjects of the study?

5. What statistical procedures are employed?

6. What are the main findings?

The 1974 reviewers were amazed to find abstracts that did not even indicate the question being addressed nor the answer obtained. In some instances it was reported that a difference was found between two groups on some test but the direction of the difference was not indicated. We had no choice but to go to the original paper or omit the study from the review. In the case of journal articles, all were read. But this was not possible with dissertations and papers presented at professional meetings. With few exceptions, dissertations and papers presented were reviewed solely on the basis of the abstract.

Other Reviews and Summaries

Two papers reviewed or summarized previous research. Weimer (358) did a critical analysis of studies that compare discovery oriented and expository instruction in the fields of mathematics, science, language, geography, and vocational education. The studies analyzed focused on retention or transfer. The author reported that no clear evidence of a single superior method of teaching was indicated. It is, perhaps, a measure of our naivete that so many researchers seem to expect some such clear indication that "method A" is superior to "method B." An instructional system is complex and most of the variables extant in the system have been shown to affect learning under some set of conditions.

We know, for example, that the personalities of both teacher and student influence learning, that the difficulty of the learning materials may interact with method of instruction, that reading level or the kind and amount of laboratory activity can influence learning, and on and on. What we do not know -- and what researchers so often fail to tell us -- is the set of conditions under which each of these variables will or will not have an influence.

We are overwhelmed by the studies that tell us that "discovery learning was found to be superior to the expository approach" and the equal number of studies that report "those under the expository presentation achieved more than those in the discovery treatment." Few reports of these studies provide enough information concerning what was done under the treatments called "discovery" or "expository" to enable the reader to infer the unique set of conditions that led to the stated result or to attempt a replication of the research.

In writing this review, Willard Jacobson's paper, "Forty Years of Research in Science Education" (154) took on new interest. Jacobson has provided a historical view of research in science education beginning with Francis D. Curtis' review of 1926. Several points are of interest. First, Jacobson noted the number of studies listed in the bibliographies of the six reviews which appeared from 1926 to 1957. The total was 623. By contrast, there are 385 entries in the bibliography of this review covering a single year. Certainly one of the reasons for the large increase in the number of studies reported is that the earlier reviews were much more selective but it still seems clear that considerably more research is being done in science education in recent years.

Of additional interest is Jacobson's breakdown of the studies reported in the past. He lists four categories; empirical, philosophical,

policy, and developmental. Over the 40 years covered by Jacobson's review, the number of empirical studies remained fairly constant. An increase in philosophical and developmental studies was noted in the 1953-1957 review of Lawlor as was a decrease in the number of policy studies. It is the decrease in policy studies that Jacobson highlights. We tend to turn up our noses at surveys and descriptive research in general but decisions still must be made and our data base is often appallingly small, biased, or both. As a case in point, much attention has been given in recent years to the declining enrollments in physics. Rowe and DeTure in the 1973 review grouped physics-related research in order to examine this problem. Is this a real problem? These reviewers have seen no data on a national sample to indicate that such is the case. There are data that suggest a problem exists but the data are either local in nature or competing explanations exist. Are some individuals reacting to local change, others simply spreading the rumor or is the problem real? Another example surfaced when a member of the Purdue faculty recently reported the results of a survey which seems to indicate that the course content improvement project materials developed under NSF funding are being used in a small fraction of the public schools. A Massachusetts audience refused to believe the report. Were their biases due to the substantial use of these materials in their own state (c.f. Whitla and Pinck (365) discussed on p. 51) or were the data reported incorrect? Data of this sort do affect our policy decisions. It is important that we have accurate information.

After reading hundreds of research reviews, the reviewers were struck by Jacobson's list of the criticisms of research contained in Curtis' second digest of research. They are worth repeating.

1. Failing to state the problem definitely.

2. Assuming the equivalence of experimental groups without taking adequate steps to insure this equivalence.

3. Securing equivalence of groups upon a basis other than that in terms of which results are measured.

4. Failing to isolate the experimental factor.

5. Delimiting too rigorously the teaching methods under investigation.

6. Assuming the definitions of the teaching methods under investigation to be standard, i.e., commonly accepted.

7. Failing to report the technique in sufficient detail.

8. Mingling findings and conclusions with details of methods.

9. Evaluating on the basis of only one criterion, when that criterion is but a single element in a more complex process or situation.

10. Employing crude subjective tests in measuring results.

11. Making gross errors in recording data.

12. Including personal opinions among the findings and introducing personal bias into the investigation.

13. Making sweeping generalizations from obviously insufficient data.

Alas, all is new but nothing changes.

Learning

Studies Based on Learning Theories Other Than Piaget

For purposes of this review, learning theory is rather loosely defined. Some of the studies reported in this section are based on clearly defined theories such as those of Ausubel or Guilford's structure of intellect model. Others deal with some principle of learning which is either generally accepted or postulated to have an effect; e.g., some studies deal with the effect of feedback on learning, others contrast learning under expository and inquiry modes of presentation. Although these latter studies are not based on well developed theories, they do seem to have theoretical implications.

Thorsland and Novak (342) relate their work on intuitive and analytic problem solving to Ausubel's subsumption theory. In this study, 25 physics students were randomly selected from a class learning college physics by audio-tutorial methods. Students were given four problems to solve in an interview format. Their performance was audiotaped and analyzed to classify students as high or low analytic and high or low intuitive. An analytic approach to problem solving was defined as a step-by-step analysis of a problem, often accompanied by use of mathematical relationships and symbols. An intuitive approach was characterized by an implicit "feel" for the subject with little or no conscious awareness of steps used in arriving at an answer. The authors contend that the analytic approach is associated with building superordinate constructs from subordinate information. An intuitive approach is identified with reconstructing necessary subordinate information from the superordinate constructs and, thus, related to Ausubel's theory. After subjects were classified, four interview tapes were selected and independently judged by four judges in order to establish inter-judge reliability of the ratings. The data indicated that the reliability of the judging was high and led the authors to conclude that it is possible to identify consistent and reliable individual differences in analytic and intuitive functioning as defined by this study. The four hypotheses tested and the results are as follows:

H_1: The analytic dimension is more highly related to scholastic ability (SAT math and SAT verbal) than the intuitive dimension. The authors found no difference in SAT scores for students with high and low intuitive ability but did find significant differences in SAT scores for high and low analytic ability students, concluding that the hypothesis was supported.

H_2: High intuitive students will achieve at a higher level than low intuitive students; high analytic students will achieve at a higher level

than low analytic students. Achievement test scores in the course supported both parts of the hypothesis.

H_3: High intuitive students will spend less time than low intuitive students in learning; high analytic students will spend less time than low analytic students in learning. Students with the combination of high analytic and low intuitive ability spent more time in learning than other groups but there were no significant main effects; thus, the hypothesis was not supported.

H_4: High intuitive students will be more efficient in learning than low intuitive students; high analytic students will be more efficient in learning than low analytic students. Efficiency was defined as the ratio of achievement to time spent in learning. The data did not support the hypothesis.

Other studies related to Ausubel's theory all dealt with the efficacy of advance organizers in enhancing learning. Shmurak (309) designed advance organizers which were matched to various cognitive styles as defined by the Sigel Cognitive Styles Test. Three experimental groups of 8th grade subjects received 1) an advanced organizer matched to their cognitive style, 2) an organizer matched to one of the other cognitive styles or 3) a non-organizer. Other students served as controls. The principal research hypothesis - that a match of student type and organizer style would produce greater learning and retention - was not supported by the data. The non-organizer was shown to be as effective as the advance organizers.

Somewhat different results were obtained in a study in a college genetics course. Scarnati (292) collected data on the knowledge of students entering the course and used these data to divide the group into high and low knowledge groups. Half of each group was given a structured overview of the course as an advance organizer and achievement by this group was compared to achievement of students who did not receive the organizer. Results indicated that students with high entering knowledge and using the structured overviews as organizers achieved more than all other groups.

In a third study, Barrow (22) gave seventh graders an advance organizer or a historical introduction to material in an activity-centered science program. He found no evidence that advance organizers enhance learning. Despite the logic of Ausubel's contention that advance organizers should enhance learning, inconsistent results reported in these and other studies indicate that we do not now know how to write such organizers in a consistent manner. Perhaps a careful review of these studies, the study by Clarke (386) which was reviewed in 1973, and other studies on advance organizers would yield some indication of the conditions under which advance organizers will lead to greater learning.

Giantris (123) studied the effect of sequencing programmed lessons on science administered to first grade children and related this to Ausubel's principles of progressive differentiation and integrative reconciliation. He found no difference in achievement between students who received the lessons in an orderly sequence and those who received the lessons in a scrambled sequence. This finding is consistent with

previous research on programmed learning which shows that scrambling frames does not reduce learning but generally fails to support Ausubel's ideas. However, it is contrary to the results that Clarke obtained where materials were arranged to reflect progressive differentiation of content and integrative reconciliation of the parts. The reasons for the inconsistent results are not revealed by the limited information contained in the abstracts. Perhaps a careful reading of the full papers by someone who is thoroughly familiar with the theory would lead to greater success.

Two studies were reported which relate to Guilford's Structure of Intellect model. Ignatz (152) used a multiple regression analysis to predict Project Physics achievement on the basis of 12 structure of intellect factors and scores on the Florida State-Wide Twelfth Grade Test. It was found that the structure of intellect factors that predicted Project Physics achievement were dependent on sex. For boys, three divergent production abilities were the best predictors whereas three convergent production factors were the best predictors for girls. The structure of intellect factors were better predictors than were the Florida Tests. In a study predicting achievement in PSSC physics, Spero (325) found that various factors of the structure of intellect model were more effective predictors than previous course grades when the criterion was achievement on the first PSSC test. However, previous course grades were more effective predictors of final grade in the PSSC course. Those structure of intellect factors that were good predictors of achievement on the first PSSC test were 1) evaluation of semantic relations, 2) cognition of semantic implications, 3) evaluation of semantic implications, 4) convergent production of symbolic systems, 5) divergent production of symbolic relations, and 6) memory of semantic classes. Those factors which were good predictors of the final grade were 1) evaluation of semantic relations, 2) divergent production of symbolic relations, and 3) divergent production of symbolic classes.

A series of studies related to the Project on an Information Memory Model were reported by Moser and his associates.* Attashani and Pesenti (14) compared the performance of children living in Libya and the U. S. on two problem solving tasks: the chemical bodies experiment studied by Piaget and Inhelder and a figural sorting task. The only conclusion reported is that information memory flow of students varied across the two cultures. In another Piaget-related study, Dean (77) tried to determine the information flow of preoperational children in doing a repeated concrete task. She then tried to establish the nature of the difference in cognition which occurred under the test condition: 1) immediate reconstruction recall, 2) immediate memory recall, and 3) delayed memory recall. The author reports that the data appeared to confirm the hypothesis of Piaget and others about the schema role for reconstruction and pure memory recall but not their definitions of memory and mental maturation. Moser (233) gave 7, 9, 11 and 15 year olds a sorting task of 14 geometric figures and then asked them to recall properties of color and shape and to identify numbers of figures in spatial locations corresponding to the display of figures in the passive learning session. As the age increased, there were more set elements constructed in the figural

* A related study is (94) reviewed on p. 15.

sorting task but the increase could be attributed to chance up to age 15. Although not discussed in the abstract, the author apparently has formulated conclusions which are related to Piaget's interpretation of mental maturation. In two additional studies aimed at development of the Information Memory Model, Empfield (100) and Sweeney (334) investigated the amount and kind of visual information processed and stored by children and the relationships between personality and information processing.

In a study of the influence of cognitive style on learning in elementary science, Walters and Sieben (357) used the Children's Embedded Figure Test to categorize students into analytic, average, and global groups. Using the Science Attitude Inventory and the Test of Science Processes as criterion measures, it was found that analytic students significantly outperformed global students on both measures. The finding that analytic students do better on a test of science processes is quite understandable but it is not quite so clear why their attitudes should be more favorable. The authors offer no explanation.

Several studies have been reported which deal with the relationship between verbal ability and science achievement. In an article written for classroom teachers rather than for researchers, Gardner (120) summarized some research dealing with problems of language in science teaching. Of particular interest is a summary of work done to determine the proportion of students at various grade levels who understand the meaning of various non-technical words frequently employed in science teaching. These are words that normally would not be defined in a science class since they are not part of the technical vocabulary. However, based on the percentages of students who were able to give correct definitions, it would appear that many of these words require attention if students are expected to understand what we are attempting to teach. This research was performed in Australia and is similar to some of the work done by Kane* on the understanding of mathematics terms among U.S. students. Similar research is needed in this country. In an interesting study by Ellis (99) ninth grade students learned about electric circuits under varying verbalization procedures. Some wrote, some talked, and some did not verbalize at all during learning to see if verbalization had any effect on achievement. Although no effect was observed, the author suggested that uncontrolled variables in the study may have masked treatment effects and further research along these lines might be of some interest.

In a study of variables that affect learning from written materials, Wilson (370) inserted questions in text material which asked for information about the text or diagrams. It was found that this procedure did facilitate acquisition of relevant information but had little effect on incidental information. This study is reminiscent of the study by the same author (392) which was reviewed in 1973. In both studies the results seem to show that procedures which force the learner to attend carefully to relevant information in the learning environment will enhance learning.

Yore (376) compared gains in reading readiness by kindergarten children who used a traditional reading readiness program with gains

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* Kane, Robert B., and others. Helping Children Read Mathematics. American Book Company: New York, 1974.

made by children who studied Science - A Process Approach materials and found no differences in their effectiveness. Byron (53) used Science - A Process Approach materials in a study involving poor readers in elementary school. He concluded that certain teacher characteristics and the use of low-reading-demand science materials were important factors influencing success in science with such students. Fronk (116) found that learning units requiring physical manipulation were easier to learn with audio-tape presentations than with written presentations. Poor readers also did better with audio-tape presentations and non-manipulative units. There was no difference in performance for good readers. Once again we may ask whether the important variable here is the attention that the learner is able to give to what is being learned. When the important elements of the learning environment are those coming from the manipulative activity, constant referral to written directions may simply distract whereas the audiotaped instructions permit the learner to maintain attention on the manipulative activity. The fact that poor readers also do better with audiotaped presentations of non-manipulative units is probably no more than a reflection of their poor reading skills.

Thirty secondary science texts were evaluated by Fletcher (110) who employed the Fry Readability Graph and Romey's Involvement Index. He found a considerable range of readability level within some textbooks as well as from one text to another. In many cases the readability level was incommensurate with the designated level of the text. We are not sure just what this means since there is some question concerning the validity of readability formulas when applied to technical materials such as science texts. We would like to see work in the area of science reading similar to the work Kane has done in adapting the Cloze procedure to measure readability of mathematics. Reading level of materials is clearly important but we have little confidence that existing formulas measure it reliably.

Tomera (345, 346) reported two studies on retention of the science processes of observation and comparison. These papers are based on the dissertation (391) reviewed in 1973 but are mentioned here because they are more accessible as the journal articles.

Inquiry and discovery learning continue to be fertile fields of research in science education. However, the terms remain poorly defined and descriptions of the teaching procedures are usually insufficient to enable the reader to determine just what kind of activities are performed under such headings. Story (330) investigated the effect of BSCS Inquiry Slides on critical thinking and process skills as measured by the Watson-Glaser Critical Thinking Appraisal (WGCTA) and the Processes of Science Test (PST). Four teachers taught both experimental and control classes. The experimental classes were exposed to two slide sequences each week for 10 weeks. In the post-test only design, it was found that students in classes exposed to the inquiry slides (whether BSCS or non-BSCS classes) performed better on the WGCTA. Other comparisons involving the WGCTA showed the following significant differences:

BSCS-X* BSCS-C*

BSCS-X non-BSCS-C

BSCS-X non-BSCS-X

On the PST test:

BSCS-X non-BSCS-C

Non-BSCS-X BSCS-C

BSCS-X non-BSCS-X

BSCS-C non-BSCS-C

Danner (74) hypothesized that inconclusive results from previous research comparing expository and discovery teaching might be accounted for by an interaction between the teaching method and the personality of the student. He suggested that students who preferred an external locus of control would retain more information learned if taught by an expository method rather than by discovery. However, individuals who show preference for an internal locus of control would perform just as well on a retention test whether taught by expository or discovery techniques. On a transfer test, it was believed that students taught by discovery techniques would perform better than those taught by expository methods. It was also anticipated that students who prefer an internal locus of control would exhibit a preference for the discovery method while externals would prefer the expository method. In order to test these hypotheses, Danner prepared two sets of lessons, one expository and the other discovery, on each of two topics (the pendulum and pressure of a liquid). Retention and transfer tests over these materials were then prepared, as was a Likert-type measure of preference for discovery or expository instruction. Each of the 160 ninth grade students in the study completed one of the lessons under a discovery presentation and one lesson under an expository presentation. (All lessons were individually administered by means of learning packets.) The results of testing immediately after instruction and 21 days later produced no significant differences due to the method of instruction, locus of control, or time of testing. There were no significant interactions. However, it was observed that the two sets of materials differed substantially in difficulty. Analyses of the data were repeated with the data for the pendulum lessons treated separately from the data for the lessons on pressure of a liquid. In these analyses it was found that the expository method of instruction was more effective than the discovery lesson when the more difficult lesson on pressure was being taught. Conversely, the discovery approach was more effective when the easier pendulum lesson was taught. Locus of control did not interact with the type of instruction as originally suggested but the behavior of internals and externals was affected by the two levels of difficulty. Although it would be dangerous to draw firm conclusions based on this study, the idea that expository presentations are

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* X indicates that the group used the inquiry slides; C indicates that they did not.

better when the material is so difficult that students are unlikely to discover important relationships on their own while discovery approaches are preferable when such relationships are more transparent is a tenable one. Additional research along these lines could be helpful.

The interaction of difficulty of learning materials with method of instruction could, for example, explain the failure of Grabber (126) to find significant differences in performance between BSCS students who were taught by a deductive-expository approach and those taught by an inductive-discovery approach. In the deductive-expository treatment, the major ideas of each unit of study were presented as advance organizers, chapters were assigned for reading along with guide questions and problems, and related laboratory work was performed at the end as an activity in verification. In the inductive-discovery approach, the initial activity was the laboratory investigation which provided exposure to the attributes of the major ideas, guide questions and problems plus suggested chapter readings followed, and the culminating activity was a discussion session in which the teacher sought to guide a discovery (verbalization) of the major ideas. Grabber did note that students who used the deductive-expository approach performed better on a retention test and suggested that this result may be interpreted as support for the efficacy of advance organizers. It may also mean that the materials were sufficiently difficult to prevent the tenth graders in the study from ever really discovering the concepts and principles being taught. Sakmyser (290) compared the performance of high school chemistry students who studied chemical equilibrium using inductive and deductive programmed materials and found no difference in achievement. However, she did find that good readers (Nelson-Denny Reading Test) in the deductive program did better than the poor readers who studied that program and good algebra students (Lankton First Year Algebra Test) did better in the inductive program than poor algebra students. In addition, data from Cattell's High School Personality Questionnaire seemed to show an interaction between treatment and various personality traits. However, the number of individuals of a particular personality type in a given treatment group was often so small that conclusions based on these data would be tenuous.

Parey (254) observed seven science lessons in each of 12 first grade classrooms. Anecdotal records were written to get detailed descriptions of events during which teachers fostered inquiry or avoided it. Of the classes observed, seven were judged to provide many opportunities for inquiry and five were judged to provide little or no such opportunity. Six performance tasks were developed to expose students to situations where they could inquire if they were inclined to do so and these were administered individually to 20 students from each class. It was found that students from classes judged to provide ample opportunity for inquiry scored higher on the performance tasks than did students from classes in which little inquiry occurred. This was taken as evidence that the performance tasks did measure inquiry. Because of the lack of tight control in this study, the results must be taken as tentative. Johnson, Ryan and Schroeder (158) investigated the effect of inquiry on the attitudes of sixth grade students. However, the variable that appears to have been manipulated is the amount of laboratory activity students had. One group of students studied from the text, Concepts in Science, and had no laboratory activity; a second group used the same text but

did have laboratory work; and the third group used the ESS unit on Batteries and Bulbs. One teacher taught all three groups with students randomly assigned to treatments. Using the Projective Tests of Attitude as the criterion measure, means of 5.38, 12.58, and 13.74 were reported for groups 1, 2, and 3 respectively. Although it was reported that the means differed significantly, no post-hoc analysis comparing the various pairs of means was reported. Apparently, the means showed that those who had laboratory activities had more favorable attitudes than those who did not.

An additional study related to inquiry teaching is the Seymour, et al. (300) report on the Inquiry Role Approach discussed in the section on Curriculum Evaluation on p. 26.

Other studies reviewed in this section dealt with self-concept, wait-time, and the influence of manipulating materials on learning. Alvord (8) gave science measures from the National Assessment and self-concept measures developed by the Instructional Objective Exchange Self Appraisal Inventory to students in grades 4, 7, and 12 and found significant correlations between the two measures at all grade levels. Lake (174) manipulated the variable of wait-time in teaching the same sequence of three lessons from the SCIS unit, Making Paper Airplanes, to groups of fifth graders. He sought to determine whether the simple extension of wait-time would, by itself, result in more student inquiry behavior and yield student responses which are cognitively more complex. It did. It should be noted that the wait-time referred to in this study is the time that the teacher waits between hearing a student response and making a comment.

Macbeth (199) taught kindergarten and third grade students four lessons from Science - A Process Approach. Prior to instruction, the students were grouped into five achievement groups on the basis of a process pre-measure and were randomly assigned within groups to manipulative and non-manipulative treatments. Those who manipulated the equipment at the kindergarten level scored higher on a process measure after instruction than did those who only observed. Although results at the 3rd grade level were in the same direction, they were not large enough to rule out the possibility that they were due to chance. The results suggest that active manipulation may enhance learning in young children (as various theories suggest) but may be less important as the child matures and develops greater verbal ability. However, Rowe and DeTure's 1973 review reports a study by Halsted (387) in which high school chemistry students appeared to learn more when actively involved in making models. Perhaps the variable of major importance in each case is simply the amount of attending behavior. There may be many kinds of learning in which attention will be just as great (or even greater) when the student is listening or reading rather than manipulating equipment whereas other learning must involve active doing to be of sufficient interest to hold the students' attention.

In another study, MacBeth (198) asked children aged 3 to 8 to sort a number of paper shapes into subsets. It was noted that there was a strong tendency at all age levels to sort by form rather than color. The author suggested that the preference for form develops before formal schooling.

A rather large number of studies were reviewed for this section but not discussed. In some instances the studies were judged to be of limited interest to science educators in this country. Most were not reviewed because the information contained in the abstract was insufficient to evaluate the research. In most cases the title of the paper will enable the reader to judge whether the study is one of personal interest. These studies are Amundsen (10), Berstein (31), Bollig (37), Fielding (107), Geeslin (122), Haley (133), Hill (143), Moore (232), Ngoi (240), Palmer (252), Penick (260), Sheehan (308), Sibley (314), Tamir and Goldminz (339), Toews (344), Walker (356), and Yanoff (375).

Piagetian-Based Studies

No theoretical model of learning and intellectual development has captured the imagination of science educators more than that of Jean Piaget. Many of the tasks used by Piaget and Inhelder in their study of growth and development of logical thought are so clearly related to learning in science that it is difficult not to see implications of their work. It is no wonder that Piaget's work has formed the foundation for so much work in science education. Still, not all of that research is well conceived or carefully executed. As Darrell Phillips (262) points out in his critique of research related to Piaget's work, Piaget's model is complex and not easily understood. Many ill-conceived studies are performed simply because the author does not understand the theory as well as he might. There are other problems too. The methodology used by Piaget is quite different from the standard research methodology taught in college courses. Since the techniques are less familiar, researchers are more likely to commit simple methodological errors which lead to questionable interpretations. Phillips describes some of the common errors in his paper which is certainly worthwhile reading for anyone who plans to conduct studies related to Piaget's model.

A number of people have attempted to train students on specific Piaget tasks or in specific logical operations with the expectation that such training will improve performance on the tasks. As early as 1961 Smedslund* pointed out that training a child to repeat memorized task responses has little lasting effect upon his cognitive development but such studies persist with a number of variations. Boulanger (39) attempted to train third grade students to reach the formal operational schema of proportions and found that subjects improved on a task which involved immediate retention of the skill taught but no such gains were noted on a delayed retention task or on tasks which involved transfer of the intellectual skills to different tasks whether these were given immediately after learning or delayed. This finding is consistent with other research in this area. Findings (reported by several authors in the past) that subjects can be trained to improve performance on a particular task are easily explained by a testing effect. Students may remember from one test to another certain information which leads to responses which result in a higher score on the task. Such a testing effect was clearly shown

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* Smedslund, Jan. "The Acquisition of Conservation of Substance and Weight in Children III," Scandinavian Journal of Psychology, Vol. 2, pp. 85-87, 1961.

by Lawson, Nordland, and DeVito (184). With a time lapse of one week between pre and posttesting, significant gains were made on three of five tasks. Interrater differences were found to be nonsignificant. There was no training in the short period between tests, indicating that gains were likely to be attributable to the affect of the pretest on posttest performance. The three tasks on which significant gains were made were conservation of volume using clay, conservation of volume using cylinders, and equilibrium in a balance beam. The authors suggested that subjects probably remembered what happened before and this influenced their response. Significant gains were not made on an exclusion task and a separation of variables task.

A number of the studies may be interpreted as tests of various aspects of Piaget's theory. In general, these studies lend support to the theory. Indeed, given the many pitfalls in any research effort, the unanimity of the support for the theory is rather striking. Only in the age at which students are likely to develop formal operational thought do the studies consistently contradict Piaget's model. In this area, it is generally found that students in the U.S. develop formal operational thought several years later than the 12-15 years suggested by Piaget. (It should be noted that the ages given by Piaget as the period of transition from one stage to another indicate the age at which one may expect 75 percent of the subjects to demonstrate the higher level of thought.)

Lawson and Renner (183) did a factor analytic study of scores on a number of tasks described by Piaget as measuring concrete or formal operational thought. The principle components analysis produced two distinct factors, with the formal tasks loading on one factor and the concrete tasks loading on the other. The results were interpreted as lending strong support to Piaget's division of logical processes into concrete and formal categories. However, it was found that students in this sample demonstrated formal operational thought at a later age than suggested by Piaget. Griffiths (128) tested a number of college students and found that the majority were not at the level of formal operation (39 percent were classified as III B). Both results are consistent with a large number of studies performed in the U.S., England, and Australia [c.f. Kavanagh's study reviewed in 1973 (389)].

Although a number of studies have shown that formal thought develops later than suggested by Piaget, the growth of logical thought through the various stages appears to be invariant and, as suggested above, is not materially affected by specific training. Bredderman (40) studied children in grades 4, 6, 8, and 10 and found a significant improvement in the ability of subjects to combine and control variables during pre and early adolescent years. This improvement was not noticeably affected by the nature of the science program studied. It was noted that initial development of controlled variables precedes that of combining variables but that final mastery was not achieved until the subjects acquired the ability to combine variables. Bart and Aviasian (23) studied the ordering of seven Piagetian tasks and concluded that concrete operations is a necessary prerequisite of formal operations. Hensley (141) used a Guttman scaling procedure to investigate the sequence of arrival at proportional thinking. The tasks (not clearly described in the abstract) in order of easiest to most difficult were Beads, Switches, Inclined Plane, and Shadows. Carlson (56) also used a Guttman scale to study the development

of space and time concepts of children in grades one through six. It was found that one dimensional concepts were less difficult than two dimensional concepts which were less difficult than three dimensional concepts. Rowe and DeTure also reviewed a study by Thiel (390) which showed that children in grades three through five experienced difficulty in coordinating multiple dimensions. This seems to contradict Piaget's belief that locations in two and in three dimensions are equally difficult.

Kishta (168) compared performance on selected Piagetian tasks and the degree of bilingualism in the subjects. The results support the idea that linguistic abilities are used according to the level of Piaget's operative structure. Dunlop (94) used an analysis based on information theory* to study the thought processes of concrete operational and formal operational subjects and found that the coding process and the storage and retrieval of information in short-term memory differed for the two groups of subjects; again, lending support to Piaget's conceptualization of concrete and formal operational thought as different stages of intellectual development.

One of the problems with work related to Piaget's theory is the difficulty of administering the individual tasks used by Piaget. A number of researchers have attempted to replace these individually administered tasks with group tests of some kind. However, when this is done one must ask whether the group tests measure the same intellectual process. Brown (45) administered individual tasks and group tasks designed to measure the same intellectual skills to students in grades 6, 8, 10, and 12. Although it was found that the group tasks yielded useful data, it was felt that the interpretation of scores on group tests and individual tests could not be the same. This finding that group tasks can yield useful information concerning various aspects of intellectual development but cannot be interpreted as being equivalent to individually administered tasks is consistent with results reported by others who have worked on the development of written tests. The obvious advantages of group tests in terms of ease of administration and objectivity of scoring do make them appealing for certain kinds of studies, however.

One such study was Raven and Polanski's (275) study of the relationships among Piaget's logical operations, science content comprehension, critical thinking, and creativity. In this study, a battery of tests was administered to fourth and sixth graders and correlational and regression analyses were performed to determine relationships among the various measures. The tests used were the Science Content Comprehension Test (SCCT), Vocabulary (VI) and Comprehension (Cl) scales from the Iowa Test of Basic Skills, Raven's Test of Logical Operations (RTLO), the Verbal (VCT) and Figural (FCT) tests from Torrance' Test of Creative Thinking, Paulus Conditional Reasoning Test (PCRT), Paulus-Roberge Class Reasoning Test (PRCRT), and the Cornell Critical Thinking Test (CCTT). The two basic questions asked in the study were: 1) Is there a positive relationship between science content comprehension and creativity, critical thinking, and Piaget's logical operations? and 2) Do children's creative and critical thinking abilities, logical operations, and comprehension of science differ between fourth and sixth grade children?

* Other studies based on information theory are discussed on p. 7.

The data clearly show that the answer to the second question is "Yes." In addition, a regression analysis which used the subscales of the RTLO to predict scores on the SCCT was interpreted to show that a substantial portion of the variance (40 percent) was accounted for by the level of intellectual development of the child. Similar regression analyses indicated that a substantial (but somewhat smaller) portion of the variance on other tests could be accounted for by the RTLO. The RTLO was also used in a study reported by Raven, Hannah and Doran (274) which showed a strong relationship between scores on the RTLO and achievement of black college students in physical science and biology (c.f. Hannah (136) reviewed on p. 31).

A number of cross-cultural studies have been done during the past twenty years and these studies have shown that individuals in different cultures do not develop intellectual skills at the same rate. One may wonder whether there are important differences in the rate of intellectual development among various groups within the U.S. Two studies were reported which deal, at least peripherally, with this question. Griffiths' (128) study of college students mentioned above found no significant difference in Piagetian level observed across racial groups. However, a study by Nordland, Lawson, and Kahle (241) suggested that acquisition of conservation concepts lags behind expectation in the group of blacks and Spanish-Americans studied. Rowe and DeTure cite a study by Johnson (388) which showed that low socio-economic status students did not perform as well on classification tasks as did their high socio-economic counterparts. The subjects in this study by Nordland, et al., came from "disadvantaged" schools. Of the subjects tested, (96 seventh graders and 506 high school students) only about 15 percent demonstrated beginning formal operational thought (level IIIA), about 69 percent were concrete operational (level IIB), 16 percent were beginning concrete operational (level IIA), and 1 percent were classified as preoperational. Interestingly, there was little difference in the percentages of seventh graders and high school students classified at the various levels. To what extent this lag can be attributed to schooling or to other cultural influences is uncertain.

Albert (5) reported an interesting study in which she analyzed the development of the concept of heat by children. She interviewed 40 children, aged 4-9, and then analyzed the resulting protocol material. The concept of heat seemed to develop over time with the idea of the concept of a "hot-body" being in evidence at ages 4-6.6, the concept of heat as something labile emerging at ages 7-8, hot-warm emerging as a single dimension at age 8, heat as an independent entity in evidence at age 8, temperature as a single dimension arising at ages 8-10, and the concept of energy as a source of heat showing up at ages 8-10. The author suggested that only an internal dynamic mechanism can explain the acquisition of concepts by the human organism.

Other studies reviewed are Ball and Sayre (18), Baruch (24), Carter and Krockover (57), Driver (95), McIntyre (221), and Triplett (347).

Behavioral Objectives

The wave of studies concerning the effect of behavioral objectives has apparently passed. There were few studies reported in 1974 which were related to objectives and those that were done tended to seek causes behind the observation that lists of objectives either help, hinder or leave the student unaffected. The exception to this generalization was a study by Martin (210) in which he found that students who were given a list of objectives during the lecture that initiated each daily module achieved more than did students who did not receive such a list. However, even here the reason for the success of the objectives treatment is alluded to in the statement that "a student was to consider his efforts in completing the module successful when he was capable of doing all the tasks specified by the objectives." It is possible that the low ability students in this basic science course simply used the objectives as a list of chores and completed more tasks than their counterparts who were not as certain of the expectations.

In an interesting study by Froelich (115), objectives were either given with a pretest or with a posttest. Indications were that the objectives given with the pretest items facilitated learning, whereas objectives given with the posttest items inhibited performance. The combination of objectives and pretest items may have served as a kind of advance organizer. But the time and attention of the student were taken away from reading and answering questions on the posttest when they read the objective prior to each question, resulting in some confusion by the students.

In a study aimed at predicting student learning, Rider (280) investigated the impact of 24 variables on mastery of sets of behavioral objectives. There was no increase in variance accounted for when any of the 24 variables was used in place of a single IQ score.

A study by Anderson (11) indicated that prior knowledge is one of the important variables in predicting student learning. She found that students having high prior knowledge of biology scored higher on immediate learning and retention examinations over a biology unit than did students with a low prior knowledge as measured by a pretest. This is consistent with most theories of learning which suggest that the existing cognitive store of the student significantly influences the assimilation of new information. Anderson also concluded that objectives classified at the higher levels of Bloom's Taxonomy facilitate immediate learning and retention to a great degree only in the high prior knowledge group, a result consistent with Ausubelian theory.

Other studies reviewed in this section were Gatta (121) and Law (179).

Formats for Instruction

In this section we have reviewed those studies which compared performance of students under audio-tutorial, televised, computer assisted, or programmed instruction. Since most of these formats were designed to provide more individualized attention to students, we have focused on those aspects of the studies which might provide clues concerning the

meaning of individualized instruction. Many investigators still refer to a program as individualized when it is only self-paced. Although self-pacing may be considered to be an important aspect of individualization, truly individualized instruction must take into account the variety of personalities and aptitudes of learners and the interaction of these entrance characteristics with learning.

Rowe and DeTure indicated three classes of questions concerning individualized instruction that need answers: 1) Under what conditions do self-directed, self-paced programs help and under what conditions do they seem to hinder progress? 2) What learner characteristics interact with the modes of presentation? 3) Are there any trends that would allow us to make some recommendations for practice?

In their introduction to the review, Rowe and DeTure summarized what has been learned from previous research. First, we know that students procrastinate when given the opportunity to pace themselves, that a diet of all one kind of presentation produces educational indigestion, and that students learn more and suffer less from procrastination if the information occurs in short rather than lengthy units. It was also found that frequent short tests produce better achievement than few long tests, particularly for middle and low ability students. Nothing in the present batch of studies seems to contradict these generalizations, but not much more has been learned. The importance of effective feedback during learning was reaffirmed and it didn't seem to matter too much how this was presented. It appeared that there was some kind of interaction between personality, cognitive style, and attitude of the learner and success in individualized programs but the exact nature of that interaction was far from clear. The more students know when they enter a course, the more they learn. It seems to be more efficient if we start instruction in the areas where they know most and proceed to areas where they know least -- but this is not new. Visual representations are important for students who can't read but of less value to those who can. Of course this doesn't hold if the concept being taught is a visual concept (such as spatial relations) or aural concepts (such as domestic fowl calls). Here the mode of presentation needs to be matched to the learning. (We might add here that students don't learn psychomotor skills by reading either!) In general it is found that students like audio-tutorial and most other types of individualized instruction (especially if they are novel) but most of the important questions concerning what makes such programs succeed or fail still plague us.

Anyone who has attempted some form of individualized instruction knows that some students have difficulty in adjusting to the new format. Students learn the rules of school early and when we change the rules, adjustment is required. Linn, Chen and Thier (190) and Slattery (318) provide evidence to reaffirm that the problem of adjustment exists. Slattery reported that difficulty was greatest for female students but no hypotheses were advanced to account for this.

In an effort to learn more about the interaction of cognitive style and learning, Rundio (288), using instruments developed at the Oakland Community College in Michigan, determined the "cognitive style maps" of 30 ninth grade biology students. These maps were used to determine a composite cognitive style profile for students who earned various letter

grades in the course. The author concluded that collective cognitive style profiles could be ascertained for students in certain teacher-determined grade categories, giving clues for personalizing instruction. Littlefield (192) proceeded along similar lines, looking at characteristics of high, "expected," and low achievers in an individualized high school biology program. The findings indicated that differences did exist between the three levels of achievers and, by combining a number of factors, a summary description characterizing each group was possible. The implication of these two studies seems to be that we can do a more effective job of individualizing instruction if we know the personalities and cognitive styles of students in advance. However, it is not entirely clear what characteristics are most important or how they can be efficiently assessed.

Confusion also reigns on the question of how much freedom of choice students should have in selecting exercises and in self-pacing. Humphreys and Townsend (149) indicated that students have difficulty adjusting to freedom and that confusion and frustration may result when students are allowed complete freedom of choice.

Gunter (131) investigated the sequencing of units in a college biology course utilizing an audio-tutorial approach. Five units were either sequenced on the basis of an analysis of the major concepts included in the five units (SBUS) or on the basis of a pretest (TDUS). In the SBUS sequence, the latter units were ones that built on concepts developed in the earlier units; in the TDUS sequence, the student simply started with the unit for which pretest data had shown the student to have the greater amount of information and proceeded to the unit which was least familiar. Within each unit, the activities were either sequenced by the teacher (TDE) or by the student (SSE) using lists of objectives as a guide for selection of related activities. At the conclusion of the study there were no differences in achievement or attitude toward the course. However, Gunter found that students who studied the units in the structure based sequence (SBUS) took twice as long as did students who studied the units in the sequence based on pretest results (TDUS). In addition, students who selected their own within-unit sequence of activities (SSE) took more time than did students who were given a sequence by the teacher (TDE). These results seem to say that we will do a more effective job of instruction if we can learn in advance what the student already knows and sequence the learning activities to capitalize on that prior knowledge. It also suggests that the teacher may be in a better position to make this kind of judgment (given that the teacher has the necessary information concerning entering knowledge) than is the student.

Another interesting result of Gunter's work was that students with high grade point averages used more time to complete instructional units and scored higher on the achievement posttest than did low grade point average subjects. This is consistent with data obtained at Purdue University over several years of experience with audio-tutorial instruction. It probably means one of two things; either low achieving students are not very able to judge when they have done enough work to master the requisite material or they are not sufficiently motivated to persist in the learning activities until mastery is complete. In either event, additional external guidance may be called for. (Studies by McCurdy (216) and Wood and McCurdy (372) discussed on p. 25 and p. 29 are also relevant.)

If the student's attitude is an indication of how much he will persevere in an individualized course, the die may be cast before the course begins. Butzow and Pare (52) indicated that attitudes toward an audio-tutorial course in college physical science "are developed early, persist, and have a strong influence." However, in a study by McDuffie (219), it was concluded that personality factors were poor predictors of achievement and attitudes toward science and audio-tutorial instruction. It appears that personality factors, attitude, and previous knowledge are related to achievement in an individualized program but just how they are related is not clear. Perhaps we are not looking at the data in the right way. Most regression analyses assume a linear model because it is easier to work with. Aird (3), however, used a curvilinear regression analysis in an attempt to determine factors which predict achievement in a self-study, computer based program in engineering. He reported that the resulting predictive models were good in terms of the variance accounted for but the abstract does not provide any details of the analysis. Aird also found that students using the CAI materials outperformed students in traditionally taught classes.

Mintzes (228) gives us some indication of the variables associated with success in individualized or traditional instruction. He measured several "biographic factors," "personality factors," and "cognitive and affective factors," and correlated these with achievement in a college biology program employing audio-tutorial techniques. Significant correlates of performance in the A-T classes were: 1) biographical factors: college major, college grade-point average, and number of college mathematics courses taken; 2) personality factors: intelligence and sobriety; 3) cognitive and affective factors: scores on the Nelson Biology Test, TOUS, and the Science Attitude Inventory. For students in conventional classes, factors correlated with performance were: 1) biographical factors: sex, type of high school, high school mathematics average, college major, and number of college mathematics courses taken; 2) personality factors: intelligence and creativity. No relationships were found between cognitive and affective factors and performance. No regression analysis was reported. There was no indication of the amount of variance accounted for by these variables.

One is struck by the fact that mathematics courses taken and mathematics grades are often found as important predictors of success in science courses. This is certainly to be expected in physics courses such as the one investigated by Naegele (235) where grade aspiration and mathematical skill proved to be the entry factors having the greatest influence on achievement. Physics courses rely heavily on quantitative skills. However, this relationship is not so obvious in biology or earth science where quantitative work is generally less prevalent. One may wonder if the correlation between success in mathematics and science achievement is not due to some measure of analytic ability such as that measured by Raven's Test of Logical Operations. It would be interesting to see some regression analyses which use tests such as Raven's or other Piaget-based tests as predictors of success.

A number of studies related to individualized instruction focused on specific instructional aids and their influence on achievement. Holliday (147) found that low verbal subjects benefited from certain verbal and pictorial representations whereas high verbal ability students appeared

to be less dependent upon pictorial representations. Keller (165) also investigated the importance of visual materials in an audio-tutorial program in geology. Other components investigated were activity, audiotape, study guides, and proctors. The most important component for learning varied for the lessons, as one might expect. Visuals were considered most enjoyable for all six lessons. That the format of presentation interacts with the content of the lesson is borne out in a study by Brice (42) who investigated the learning of an audio concept (domestic fowl calls or sound signals) when students used audio only, visual only (spectrograms), or audio-visual stimuli. The results indicated that for the complete audio concept, learning was significantly better through the use of one of the audio containing media.

Learn (185) evaluated the contribution made to the attainment of certain relational concepts of physical science by computational procedures and non-computational problem solving techniques. He found that only the upper one third SAT math students benefited from the computational procedures while the lower two-thirds achieved better using verbal procedures.

Barnes (21) used group discussions as a supplement to audio-tutorial instruction and found that the discussion groups achieved more and had more positive attitudes.

Modeling may be an effective strategy for certain types of learning. In a study reported by DeTure and Koran (81), fourth grade students were prepared for a laboratory investigation by watching a videotape model showing peer leaders engaged in the steps of an experiment and verbalizing their acts. Control students did not view the model but had an equivalent time to practice the directions for the experiment. Subsequently, both groups conducted the same experiment while trained raters observed their behavior. Those students who viewed the model produced significantly more positive behaviors and fewer negative behaviors than did the control group.

In a study involving laboratory work with college chemistry students, Costa (67) compared the effect of three treatments which varied in the degree of abstractness and found no difference in achievement or attitude. In another study involving college chemistry laboratories, Sollimo (322) investigated the usefulness of an audio-tutorial approach. No control group was used in the study but the author reported that the audio-tutorial approach resulted in significantly lower attrition rates in general chemistry.

Three studies investigated the effect of feedback on performance in audio-tutorial programs. Hunt (150) compared the performance of students receiving immediate reinforcement and feedback with a group that did not receive immediate feedback. Since the efficacy of immediate feedback is a long established principle of learning, the finding that the group which received immediate feedback performed better is no great surprise. Martin and Srikameswaran (211) provided feedback to students in a college chemistry course through frequent testing and found that these students performed significantly higher on the final examination in the course than did students who did not have frequent tests. Bush (49) compared three types of formative testing in his audio-tutorial course in high school biology. One group of students took oral tests weekly, another

group took written tests, and a third group took both. No difference was found in achievement on a summative evaluation.

There were additional studies in this section which may have implications for individualized instruction but the abstracts did not contain enough information to judge what these implications might be. Marcy (204) discovered that students in a self-paced course did better but took more instructor time and had a much greater attrition rate than did students in a lecture-recitation and programmed text groups. Parker and Mertens (256) compared the effects of programmed and conventional instruction in college biology on the test and discussion performances of students. They found that the programmed group performed better on achievement tests and that the programmed textbooks enriched classroom discussions. Siddiqi (315) compared achievement of PSSC physics students using autoinstructional materials with achievement under conventional instruction. The auto-instructional materials won.

In one of two studies related to televised instruction, O'Brien (245) found that televised instruction on problem solving attitudes was modestly successful with fifth and sixth graders in urban settings but regular classroom instruction proved superior in changing attitudes of students in rural settings. In the other study, Levine (187) failed to find any differences in achievement or attitude between community college chemistry students who took a course via closed-circuit television and those who attended lectures and recitations.

Additional studies reviewed in this section are Anderson (12), Beatty and Hathaway (27), Castleberry, et al. (59), Christensen (60), Crocker, Bartlett and Elliott (69), Doty (88), Francis (112), Fritz and Szabo (114), Hoffelder (144), Kelly and Monger (166), Love (195), Lowry (196), Mallon (203), Marlow (208), McElhattan (220), Mershimer and Qutub (224), Nunemacher (244), Padgett (251), Pare (253), Parker (255), Penick (260), Redditt (277), Sasscer (291), Shaub (306), Starr and Schuerman (329), and Thompson (341).

Curriculum Evaluation

Most studies reported in this section fall into two categories; those which provide evaluative data on specific science curriculum projects such as SCIS, ISCS or Project Physics and those which are attempts to evaluate a specific, local program of study. In addition, there were a few studies which dealt with the techniques of curriculum evaluation. It should be noted, however, that studies which focused on individualized instruction, audio-tutorial, computer assisted instruction, and similar instructional strategies are reviewed in the section "Formats for Instruction."

It is assumed that many readers will be particularly interested in studies related to curricula at a particular grade level or a particular subject. Consequently, the reviews are grouped into elementary, junior high, biology, chemistry, physics, physical science, and miscellaneous categories. Studies carried out at the college level are found under the subjects to which they pertain.

Elementary. Nine studies were reported which deal with curriculum materials used in elementary schools. Three of the nine studies dealt with Science - A Process Approach. Novinsky (242) randomly selected 30 students from fifth grade classes using Science - A Process Approach and 30 students from classes using other materials. He then administered the STEP Test, the Group Test of Creativity, and an attitude survey. No differences were found in the results on the STEP test but results on the other two measures indicated superior achievement by the Science - A Process Approach students. Information contained in the abstract was not sufficient to rule out the possibility that the results might be biased by uncontrolled factors in the selection of classrooms from which the sample was drawn. Vejdovec (353) also used the STEP test to compare fifth grade students in classes using Science - A Process Approach with students in classes using the Lakewood (Ohio) science program. Vejdovec used a 2x2x2 factorial design with treatment, intelligence and sex constituting the three factors. No main effects were detected, but a treatment-ability-sex interaction suggested that girls of low ability in the Science - A Process Approach classes performed better than those using the Lakewood program. This result was not explained in the abstract. The limited sample (n in each cell = 15) used in the study increases the possibility that the result is spurious.

In an interesting study by Judge (160), the development of observational skills in preschool children was compared for students in Science - A Process Approach, Montessori, and conventional classes. Students in the Science - A Process Approach and Montessori classes performed equally well. Both groups surpassed the performance of students in the conventional classes.

Three studies focused attention on the Elementary Science Study (ESS) materials. Barksdale (20) compared ESS to conventional (not described) classes using tests of achievement in problem solving and science attitude developed by the investigator. Achievement data were analyzed using a multiple classification analysis of covariance procedure and the attitude data were analyzed using chi square. Analyses were done by age, race, sex, experience in the program, and treatment. Significant differences in achievement were reported in the abstract but not the direction of the differences. It was also reported that students in the ESS program had more favorable attitudes. Blomberg (33) studied the effectiveness of three methods for teaching ESS units in sixth grade classes; audio-visual, reading-lecture, and laboratory. No differences were found. Vanek (351) compared third and fourth grade students using ESS units with students using the Laidlaw Science Series on classification skills, science achievement, and science attitudes. No achievement or classification skill differences were noted but ESS students had more favorable attitudes ($P < .1$).

Only one study was reported pertaining to the Science Curriculum Improvement Study (SCIS). Hofman (145) compared attitudes of eight year olds studying SCIS with those using Concepts in Science (Harcourt Brace Jovanovich, Inc.) and found no substantial differences.

Unified Science and Mathematics for Elementary Schools (USMES) is a relatively new curriculum for elementary schools which stresses the development of problem solving skills. Initial reports on the evaluation

of the program are somewhat encouraging but the data collected so far appear to be too limited to draw firm conclusions. The general report of the USMES evaluation program (350) summarizes data from teacher interviews, evaluation based on the "Notebook Problem" (304) and evaluation based on the "Playground Problem." The teacher interviews indicate that the teachers of the program believe that students increase their ability to solve problems as a result of the program and the results from the Notebook Problem support this opinion. However, the results from the Playground Problem do not. Difficulties in administering and scoring the Playground Problem task are cited as possible explanations for the lack of corroboration. The task is not sufficiently described in this general report to evaluate this judgment.

The Notebook Problem is described in a separate report (304) and is of some interest. Students were randomly selected from USMES and control classes and individually tested. The test consisted of giving the student three notebook samples which differed in size, number of pages, number of lines per page, and cost. Students were then asked to select the best notebook for math and science work. In the results from a pretest given at the beginning of the school year, USMES and control students cited non-measurable reasons for their selection and based these reasons on personal opinion. In posttests administered to different students randomly selected from the same classes, USMES students cited measurable reasons for selection and based these on tests (such as counting the pages and calculating the cost per page) that they actually carried out or suggested. In contrast, there was no change in the results for students in the control classes. This was a pilot study. Some problems were encountered in test administration but the consistency of the results across classes and test administrators suggests that these administrative problems did not materially alter the result.

Another phase of the USMES evaluation has sought to determine whether the curriculum results in changes in classroom structure and interaction patterns. Shapiro and Aiello (305) report, on the basis of systematic classroom observations, that the same amount of large group instruction occurs in USMES and control classes. USMES classes devote more time to small group instruction whereas the control classes devote more time to individual activity. Changes in classroom structure appear to be more frequent in USMES classes. Within the large-group mode, USMES classes were characterized by higher levels of students contributing ideas and debating and by lower levels of responding to closed-ended teacher questions, reiterating of ideas, and random conversation. Within the small-group mode, USMES classes were characterized by more child-child and less child-teacher interactions. As is the case with most classroom interaction studies, the results showed what occurs in the classroom but did not assess the value of what occurs. It is entirely possible that USMES and control classes were utilizing the structure and interaction patterns most appropriate for the respective curriculum materials.

Junior High. Three studies in this section involved the Intermediate Science Curriculum Study (ISCS). Bardsley (19) reported a study of parent reactions to supplemental report cards which indicated the objectives their children had mastered in the ISCS program. He found that the parents who received such supplemental reports had more favorable attitudes toward the grade reports and the science program than had parents who

received only the normal report card. Martinez-Perez (213) compared the self-concept, attitude toward science, self-grading, and teacher grading of students in ISCS and non-ISCS seventh grade classes. No differences were observed other than that the ISCS teachers in the study gave lower grades than the non-ISCS teachers.

In any self-paced program such as ISCS, the ability of the student to direct his own learning activities is clearly important. McCurdy (216) asked teachers to select the top 15 percent and bottom 15 percent of their ISCS classes. The teachers were then asked to administer an inventory which asked students to rate themselves on various aspects of self-directedness. (See the discussion of Wood and McCurdy (372) on p. 29). Those students in the high achievement group had significantly higher ratings on self-directedness than did low achievers. One interesting reversal was observed on "Adapting to the Curriculum" which was a measure of the students' willingness to skip sections that they already knew. Low achievers were more confident in skipping than were high achievers. This could reflect less ability on the part of the low achievers to accurately assess what they knew or a more conservative behavior on the part of high achievers. McCurdy points out that Torrance and others* have noted that high achievers tend to be conformists. (More discussion of individualized instruction is found in the section "Formats of Instruction").

Retherford (278) reported the results of a survey of teacher reactions to the Time, Space and Matter program. Most of the data collected are of little interest to anyone not considering adoption of this program. However, it is of interest that 40 percent of the people teaching the program were non-science majors, 28 percent were biology majors, and only 13 percent were earth science majors, an area of major emphasis in the program. In view of the fact that Retherford received a 79 percent return from the 201 school systems that were sampled from 28 states and the District of Columbia, these data should be fairly representative. If they are, this study points up a serious problem: teachers being assigned to areas where they have little formal preparation. It is little wonder that 93 percent of the respondents indicated that they needed special training to teach the program.

Earth Science. Two studies were reported dealing with the Earth Science Curriculum Project (ESCP) but both deal with side issues. Green (127), using the TOUS test, compared ESCP to a "lecture-demonstration" approach for general science. He found that students in the ESCP group scored higher on Areas II and III of the TOUS. However, information contained in the abstract suggested that the study lacked sufficient control to merit generalization of this result beyond the classes used in the study. Dod (84) used the McFee Metric Test to compare the knowledge of metric measurement gained by students in the ESCP program with knowledge gained by students using the Metric Supplement to Mathematics. Scores of all students were low, with the ESCP group scoring only slightly better than a control group which had received no instruction. Students

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* Torrance, E. P. Guiding Creative Talent. Prentice Hall, 1962.

Flescher, I. "Anxiety and Achievement of Intellectually and Creatively Gifted Children." Journal of Psychology, Vol. 56, pp. 251-268, 1963.

using the Metric Supplement to Mathematics did score significantly higher than the ESCP group.

Biology. Of those biology studies reported, by far the most interesting was the evaluation of the Inquiry Role Approach (IRA) to BSCS biology conducted by Seymour and his associates (300). This study involved the development of an implementation model for IRA, the development of evaluation instruments, and an evaluation of the IRA materials in a number of schools. Reference 300 gives a complete, technical report of the study, reference 301 discusses only the adequacy of the implementation, reference 302 deals with the development and validation of the test instruments, and reference 303 summarizes the evaluation of student performance. Those involved with field testing of curriculum materials may be interested in the methodology used and should refer to the complete report (300); others will probably find one of the shorter reports sufficient for their purposes.

There were a number of hypotheses tested in this carefully designed field test. Space does not permit a thorough review of all aspects of the study. In general, the questions investigated and the results are as follows:

1. Do students in classes in which IRA is implemented demonstrate the knowledge and skills which the program materials are designed to develop? Yes. Results generally show that students in classes where IRA was adequately or very adequately implemented increased their inquiry skills during the year.

2. Does student performance in IRA classes compare favorably with student performance in non-IRA classes? Students in IRA classes developed better skills of inquiry but learned less biology content than students in non-IRA classes. Differences in content scores were probably due to less coverage of content in the IRA classes since some time was devoted to inquiry development.

3. Is there a difference in performance of students in classes where IRA is adequately implemented and in classes where it is inadequately implemented? Probably. Only one teacher in the study inadequately implemented the program. Students of this teacher demonstrated less inquiry skill development. However, since there was only one teacher in the inadequate category, the result could be due to factors other than the degree of implementation.

Only one additional study dealing with biology appeared to be of interest. Lucido (197) developed a new laboratory program for general college students which focused on activities very closely related to everyday experience of the students. Lucido failed to find any difference in performance between students in his laboratory program and the established program using the TOUS, Watson-Glaser Critical Thinking Appraisal, and course achievement as criterion measures. However, with increasing interest in course materials which are "relevant," readers may be interested in looking at the laboratory materials that were developed to determine whether they would be of use in other teaching situations.

Chemistry. Two studies were reported which deal with the Interdisciplinary Approaches to Chemistry (IAC) materials developed at the University of Maryland. Heikkinen (140) developed an attitude scale and used it to compare the interest in chemistry demonstrated by IAC and non-IAC students. He found no difference in attitudes between IAC and non-IAC students or between males and females. He did find that all attitudes grew less favorable during the school year. Hearle (139) developed a laboratory skills test which he used to compare IAC and non-IAC students. He found that IAC students demonstrated greater achievement of manipulative skills. Perhaps of more interest was the low correlation found between ability to learn content and ability to learn laboratory skills. Laboratory skills may be very important for occupations such as laboratory technicians. We probably do an inadequate job of assessing aptitude for such occupations when we rely entirely on test scores which result from written examinations.

Lindsay (188) compared a student-centered, teacher-centered, and CHEM Study approach to high school chemistry and found that those in the student-centered approach achieved more and had more increase in scientific interest than had students in other approaches. However, there were no differences in critical thinking. Unfortunately, the abstract contained insufficient information about the nature of the approach described as student-centered to enable the reader to determine what variables in the learning environment actually contributed to the differences found. In addition, the facts that all three approaches involved only one class of students (total sample = 76) and that all groups were taught by the same teacher make it impossible to generalize the result of this study with confidence.

Kempa and Dube (167) report a follow-up of a 1966 study which showed that students in Nuffield chemistry had more favorable attitudes toward chemistry than had students in non-Nuffield classes. In Kempa and Dube's follow-up study, the opposite was found. Two factors probably account for the reversal. When the 1966 study was done, Nuffield was new and it is likely that a Hawthorne effect was operating. In addition, since 1966, non-Nuffield courses have been drastically revised. Kempa and Dube's 1971 study showed little difference in attitude among high ability students but low ability non-Nuffield students had a much better attitude. They suggested that the "discovery, problem solving" nature of Nuffield was less satisfying to low ability students than was the "fact-oriented" non-Nuffield syllabus. It is quite possible that many of the low ability students did not operate at Piaget's formal operational level and found that the non-Nuffield material was easier to comprehend at the concrete operational level; thus, the more favorable attitudes. Such a proposition was not investigated in this study but might be worth studying.

Longmire (193) used a regression analysis to predict success in college chemistry. Since the study was limited to one class at one college, the resulting prediction equation is likely to be of little utility to others. However, it is of some interest that the single best predictor of success in college chemistry was preparation in high school mathematics. This result is consistent with several other studies and calls attention to the importance of quantitative skills in college chemistry. Recognizing this problem, Ramey (273) decided to try to do something about it. He developed a diagnostic mathematics skills test and administered it to

freshmen enrolled in college chemistry at Indiana University. Deficiencies which were identified were then remediated via programmed materials. Remediation resulted in gains in mathematics and gains in chemistry achievement. Although the abstract does not give sufficient information to enable others to replicate the procedures, communication with the author might lead to information which could be useful at other institutions.

In another study which investigated the relationship between mathematics instruction and achievement in chemistry, Goldman (124) presented to a group of high school sophomores a mathematics program that stressed application of mathematical skills to problem solving of the type encountered in high school chemistry. Other sophomores took the normal mathematics offering and served as the control. A mathematics test including problems of the type normally discussed in mathematics classes but also directly applicable to the field of chemistry was constructed. The test was administered at the beginning of the mathematics course, at the end of the mathematics course, and then at the end of the chemistry course taken the following year. Although the experimental group scored higher on this test at the end of the mathematics course, there was no difference in performance at the end of the chemistry course. In addition, it was found that the students from the control group scored higher on the ACS-NSTA chemistry examination given at the end of the chemistry course. The description of the study was insufficient to allow one to interpret the cause of these results. However, the fact that attrition in the experimental group was over 50 percent while attrition in the control-group was only about 5 percent suggests that some variable other than the treatment was operating and possibly biased the result.

Four studies were reported which dealt with student evaluations of college teaching. In a group of articles appearing in the Journal of Chemical Education, Schaff and Siebring (294) reported the results of a questionnaire sent to chemistry department chairmen and text book authors asking their opinions concerning various means of evaluating teachers, Larsen (176) surveyed a number of students to see what they considered when they filled out instructor ratings, and Cornwell (66) looked at the results of student ratings in an effort to determine what extraneous factors might bias the ratings. Larsen received such varied responses to his inquiry that he was not able to do much with the data. Schaff found little of interest other than that student rating was the most common technique used for teacher evaluation. Cornwell, however, did report some findings that could be of general interest. He found that there were significant differences in the ratings given by students in different class sections (under different instructors), that student ratings of the same teacher in the same course were relatively stable from year to year, and that if the class size was greater than 20, the size of the class had little effect on student rating. For classes of 20 or less, however, teacher ratings tended to be somewhat higher. Cornwell also found that ratings on a few questions varied from one course to another and from one subject to another but, for most questions, these variables seemed to have no influence.

Zelby (379) argued that student evaluations of faculty can lead to deterioration of education if used improperly since teachers can "teach for the test" and that this will encourage stereotypic teaching. Whether college faculty are really that concerned about how students rate them is debatable but in no way affects the validity of Zelby's research. He

alternated the way that he taught two different courses and then compared the evaluations obtained under alternate procedures. Zelby reported that he got much better evaluations when he stuck close to the book and encouraged recall rather than analysis. He got poorer evaluations when his lectures supplemented the text and emphasis was placed on higher cognitive abilities. This study shows that student evaluations are sensitive to differences in teaching style. It is interesting to note that the ratings obtained for the two different courses when taught by the same style were very similar even though the students in the courses were very different. This suggests that teaching performance may indeed affect the ratings more than does student background.

Physics. Only two studies are reported which deal with the evaluation of curriculum materials in physics. In a study, conducted in the Philippines, Deauna (78) used a 120 item achievement test which she constructed to compare physics achievement of students who were using materials developed by the Science Education Center of the University of the Philippines with achievement of students in conventional courses. Half of the teachers in the study had been trained at the Science Education Center while the other half had not. Using a 2x2 factorial design, Deauna found no differences in achievement due to curriculum materials and no interaction effects. She did find that students of SEC trained teachers achieved higher scores than did students of non-SEC trained teachers. In addition, scientific attitudes of students of SEC trained teachers became more positive as measured by the Scientific Attitude Inventory developed by Sutman and Moore. Since the nature of the training received by teachers at the Science Education Center and the procedures for selecting teachers for training were not described in the abstract, it is not possible to infer causes of the increased achievement noted for students of SEC trained teachers.

Miller (225) investigated the value of computer based dialogues to assist teachers in the introduction of Project Physics. The computer materials were used with a group of teachers invited to a conference devoted to the use of these materials and with a group of teachers participating in a summer institute devoted to Project Physics. Although the conference participants reacted favorably to the computer based materials, the institute group did not. Apparently the latter group preferred working with other instructional materials available in the institute. In view of this preference for more conventional instruction and the present cost of approximately $12 per hour of instruction via computer, the materials developed appear to have marginal value.

Physical Science. Wood and McCurdy (372) investigated the relationship between students' ability to direct their own learning and their achievement in the individualized Nebraska Physical Science Project (NPSP). (A related study by McCurdy is reviewed on p. 25.) In this study, a group of NPSP teachers were asked to identify the top and bottom 15 percent of their students. These students were then asked to rate themselves on eight characteristics believed to be indicative of their ability to direct their own learning. The characteristics and the mean ratings of the top and bottom 15 percent are shown in the table. Ratings were on a scale of one to five, with five indicating the greatest amount of self direction.

TABLE I

Student Ratings of Self-direction Characteristics

		Top 15%	Bottom 15%
1.	Operate independent of teacher direction	4.0	3.3
2.	Seek answers to questions without assistance	2.8	2.8
3.	Use class time effectively	3.0	2.4
4.	Plan a work schedule	3.5	2.6
5.	Use study skills	4.2	3.3
6.	Use curriculum materials without assistance	3.4	3.0
7.	Skip activities already mastered	2.8	2.8
8.	Work at a pace commensurate with ability	3.3	2.6

The differences in the resultant ratings were statistically significant for all items except 2 and 7. When the data were analyzed by sex, there were no differences in the responses of males and females in the top group. Females in the bottom group rated themselves higher on 3, 4, 5 and 8 while the males in this group rated themselves higher on 7. The authors suggested that the results of the study indicated that students should be pretested on their perception of self-direction before admission to an independent study course. However, there is no indication from this study that students had the perceptions indicated by the results at the time they entered the course. It is quite possible that the perceptions found developed as a result of experience in the NPSP course. If this is the case, pretesting would be of little value.

Miscellaneous. In addition to the studies reported which deal with evaluation of specific curriculum materials, Welch (359) has described the process of curriculum evaluation itself. This general discussion described various approaches that may be taken to evaluate curriculum materials.

A number of studies dealing with curriculum evaluation were reviewed but not discussed in this section. Some were not discussed because they were of purely local interest, others suffered from very poor design, still others gave such limited information in the abstract that a review was not possible. In most cases the title of the paper provides sufficient information to allow the reader to decide whether the paper would be of interest. The references are Alford (6), Ameduri (9), Boes (35), Crilly (68), Driscoll (92), Hall (134), Markman (207), Miller (226), Newton (239), Pascoe and Shepherd (257), Ridky (281), Rietti (282), Roxas (287), and Ryman (289).

Tests

In the field of evaluation, one must recognize and be able to discriminate among the various functions of evaluation. Testing instruments will differ according to whether the goal of the evaluation is to acquire evidence about individual students or to make judgments concerning a particular curriculum format. The major national curriculum projects have been concerned with both summative and formative evaluation during their developmental periods. Considerable effort has also been made to tease out those factors that provide some indication of the differences in outcomes to be expected when students enroll in Project Physics, for example, as opposed to a more traditional curriculum. As difficult as it may be to describe what has happened after certain types of instruction, it is even more difficult to predict what will happen if a student elects a certain academic program. In this regard we need more instruments that yield high predictive validities, simply because too many administrative decisions are based on too little information about student ability and potential for success.

In the latter category, we can report two such efforts, each very different in format and intended use. Hannah (136) focused on the problems of predicting success in the physical and biological sciences at a four-year black, liberal arts college. Six different tests were employed in this effort: the ESCP Test of Science Knowledge (Form S), The BSCS Comprehensive Final Examination (Form J), the Iowa Silent Reading Test (Advanced Form A_m), Raven's Test of Logical Operations, the Paulus Conditional Reasoning Test (Form Z-Assessing), and the Paulus-Roberge Class Reasoning Test (Form X-Assessing). In a sample of 123 black freshmen, it was shown that the Raven's Test of Logical Operations was the best predictor of achievement. We need to know, and someone should perhaps research, whether these results hold in general for other populations. Moreover, the fact that the Test of Logical Operations hints strongly at Piagetian cognitive levels and their influence on performance leads us to urge that further studies focus on these possible correlative attributes and their practical significance.

At the 1971 Annual Convention of the National Association for Research in Science Teaching, Denny (80) reported the development of the Mathematics Skill Test (MAST). The test was reported to be highly reliable (0.97) and correlated extremely well ($r = 0.8$) with the ACS-NSTA High School Chemistry Test. There was some concern, at the NARST meeting, whether the extremely high reliabilities of the test (and its subscales) were, in fact, themselves "reliable." We are pleased to report that this test has been further validated by examining its potential as a rostering tool for chemistry enrollment. Tenth grade chemistry students were given the MAST during the Spring, prior to enrolling in eleventh grade chemistry. Based on the MAST scores, teachers placed the higher scoring students in advanced chemistry and the average or below in general chemistry with varying degrees of emphasis. Those who scored below the average were given mathematics remediation prior to enrollment. Some students were advised not to take chemistry as a result of poor performance on MAST. In one sample MAST was correlated with final course grade $r = 0.36$. This correlation was statistically significant, although the magnitude of the relationship was not very large. In fairness to the MAST, however, final course grades frequently do not correlate well with predictors because of the many variables

that often enter into the decisions regarding a course grade. In a separate sample, the ACS-NSTA High School Chemistry Test was used as a correlate. The MAST was found to correlate well ($r = 0.73$) with the ACS raw score. Even the subtest scores yielded correlations of the order of 0.7, with the exception of graphing ($r = 0.4$). It should be noted that those who took chemistry although advised against enrolling either received D's, failed, or dropped the course. We would like to see whether MAST will perform this well in such related subject matter areas as physics.

Several studies were related in some way to the efficacy or ability of the various tests of science processes or tests of understanding science. Most notable of these tests is the Test on Understanding Science (TOUS), a "standard" that has been utilized quite extensively since its development. The Science Process Inventory by Welch is equally well-known and has been used fairly often as a substitute for TOUS. Aikenhead (1, 2) has taken each of these tests and combined them in such a way as to maximize their utility as instruments for providing formative evaluation of curriculum materials. The procedures and outcomes were reviewed by Rowe and DeTure in 1973, but the studies are mentioned here because of their increased accessability as journal articles.

Doran, Guerin and Cavalieri (87) looked at three other tests that are purported to measure the so-called "Nature of Science" objectives. These were the Nature of Science Scale (NOSS), the Science Support Scale (SSS), and the Test on Social Aspects of Science (TSAS). The tests were administered to 300 high school students, grades 9-12, each test having been administered to a separate one-third of the sample. It was reported that items used to measure broad areas of the nature of science (NOSS) were not related to the items measuring pertinent or specific areas of this domain (TSAS and SSS), i.e. each instrument was measuring a separate domain. The authors proposed a domain of the "Nature of Science" for the purpose of eliciting critical response and suggestions for future research in this area.

In another attempt at testing for the elusive "nature of science," Jungwirth (162) administered the TOUS test to 9th grade slow learners, 9th grade regular pupils, 10th grade BSCS students, and 12th grade BSCS pupils in Israel. In addition, the test was administered to graduating students and to professors at Hebrew University. The author reported that several of the items were lacking in validity because of honest differences of opinion in the domain of philosophy of science as well as "misguided linguistic analyses." He suggested that appropriate definitions of terms be used in the stems of these "problem" items. We would suggest that interpretation of the stem may be part of the validity of the item, i.e. how the stem is interpreted may well reveal the respondent's understanding of the "nature of science."

Rowe and DeTure suggested several times in their review that factor analyses be performed on various tests to reveal more clearly just what a particular test is measuring. Bates (26) attempted to identify independent subscales among the 135 items of the Science Process Inventory by subjecting the items to a factor analysis. Because of the very low correlations between items, the factor analysis of the whole test did not provide interpretable factors. However, an analysis of 43 items selected on the basis of moderate difficulty level and demonstrated discriminating

power did suggest five factor scales of three to four items each. The author suggested that these "protoscales might be useful in developing scales of 10-20 items each."

Durkee (95) reported a study in which 29 high school juniors and seniors attending a summer institute for talented students were assessed on three variables: understanding the nature of science (measured by TOUS), physics achievement (PSSC Test of General Course Objectives), and Critical Thinking Ability (Watson-Glaser Critical Thinking Appraisal). Pre- and post-assessments was made on the first two variables. No significant gains were reported on the TOUS test. A small (2.6 points) but significant gain was made on the PSSC test. Further, the results showed, that for this sample, understanding science and scientists (as measured by TOUS) was largely independent of Critical Thinking Ability and Physics Achievement. The author suggested that the lack of gain on TOUS might be a result of a ceiling effect. He offered as another possibility the lack of items on TOUS dealing with topics thought to be important in understanding the nature of science. It is also possible, and perhaps equally plausible, that the experience itself did not add to the students' understanding of science.

As teacher educators, we have been somewhat disturbed by the fact that, despite our attempts to reverse the situation, teachers continue to question and write test items that are predominantly in the lower levels of Bloom's Taxonomy. The findings of Billeh (32) reinforce this to some extent. His study was designed to identify the pattern of cognitive processes implied in teacher-made examinations in secondary school science in Lebanon. It was found that at all levels (grades 7-10), through all subject matter, teacher status (whether part or full time), years of experience, and depth of training, teacher-made tests contained 72 percent knowledge level questions, 21 percent comprehension, and 7 percent application. In addition, no correlation existed between level of question and subject matter taught. One unsettling piece of data is that a moderate positive (0.53) relationship existed between the number of knowledge level items and years of experience. Is this peculiar to Lebanon or might we find the same results in this country and elsewhere? If so, the implications are serious.

While the above study focused on teacher-made tests, Fast (104) elected to examine the ACS-NSTA High School Chemistry Tests in order to classify the items according to the six cognitive levels of Bloom's Taxonomy. He found that approximately 40 percent were at the Knowledge level, 25 percent were each at the Comprehension and Application level, while 10 percent were at the Analysis level. It was further noted that the Application level items were most discriminating, followed by Comprehension and Analysis. The Knowledge level questions had the lowest discrimination index.

At a time when we are emphasizing strongly the inquiry-oriented or interactive style of teaching, the lack of valid and reliable instruments to assess such activity is distressing. Such an instrument has been developed by Butt and Wideen (50) and appears to hold promise for the kinds of evaluative mechanisms we need in this area. The instrument as reported focused on the interactive characteristics among students, the environment, and teacher in elementary and junior high science classrooms.

Its purpose is to provide a measure of openness and inquiry orientation. The Science Classroom Observation Form IV (SCOF IV) resulted from an extensive item preparation and subsequent review and field testing of the first three forms. The final version contained 39 statements relating to characteristics of science classroom interactions. The statements are rated on a five-point scale. Utilizing a sample of 1165 students from 47 classrooms, the authors reported a reliability of 0.74 and an interobserver consistency of 0.86. The mean score over 43 classrooms was 108. The total SCOF IV scores had a positive correlation (r = 0.39) with students' perceptions of their own classroom. Whether this latter figure was a good measure of the concurrent validity of the instrument is not clear, since no validity or reliability figures are reported for the instrument used to measure students' perceptions of their classrooms. Factor analysis revealed eight primary factors and three secondary factors. The authors reported that further research was under way to ascertain the usefulness as well as reliabilities and validities of the subscales.

In a study by Mitchelmore (229), graduate student perceptions of ideal and actual instructor behavior, the match between these behaviors, and relationships of these variables to student and course characteristics were investigated. Students were given a 54 item questionnaire related to ideal instructor behavior on four dimensions: Consideration, Interactive Facilitation, Motivation, and Work Facilitation. The student variables were: Need for Dependence, Years of Graduate Study, Sex, Freedom in Choice of Course, Previous Courses with Instructor, and Age. After seven weeks, data on actual instructor behavior were collected along with course assessment data. The 27 best loading items from the factor analysis were used to define the dimensions above and to calculate dimension scores (the mean response to the items on each dimension). Among the findings were that dimension scores had reliabilities of 0.80 to 0.89 and were correlated with instructor descriptions of student involvement. Also, that graduate students tended to choose areas with preferred amounts of interaction and work facilitation (the latter having to do with the instructor's ability to plan effective presentations, define roles, and provide resources).

The development of tests to measure attitude and scientific thinking was reported by Sweeney (335). The latter test was designed to be free of scientific terminology. This test consisted of items measuring skills in the areas of: 1) identifying parts of scientific method, 2) relating evidence to hypothesis, 3) controlling variables, 4) relating evidence of conclusions, and 5) interpreting data. The attitude test was made up of items based on responses of graduate students, supervisors, and teachers of science to a questionnaire designed to elicit attitudes toward 1) science, 2) scientists, 3) science and society, 4) science teachers, and 5) science teaching. A factor and item analysis produced a science subscale and a science teaching subscale. The science subscale showed three factors as did the science teaching subscale.

Lindstrom (189) constructed a test to determine the relationship between the number of hours of college work completed by students in biology and their attitudes concerning the importance of various aspects of biology for high school teaching. He also attempted to find out whether instruction in science methods could shape these attitudes. There was no relationship between number of hours of biology and attitude toward

teaching certain topics. However, the methods course did have a significant influence with regard on students' attitudes regarding intellectual processes, anatomy and physiology, and ecology.

In a study conducted in Australia, White and Mackay (364) developed an instrument to test the congruence between 1) children's and scientists' perceptions of desirable attributes of scientists, and 2) children's self-perception and scientists' perceptions of desirable attributes of scientists. Such a test would measure, for example, the extent to which curriculum projects are promoting this congruence. Each of the tests are ipsative in the sense that they focus on the comparison of traits within individuals rather than on comparison of the absolute strengths of these traits for different individuals.

Golmon (125) attempted to assess opinions about science teaching as expressed by pre-service science teachers. He developed a 20-item test made up of statements that reflected current thinking about teaching methodologies and curriculum developments at the secondary level. For the most part these statements placed emphasis on the investigative nature of science and the related processes. An interesting result was that pre-service pretest mean scores and inservice mean scores were essentially the same, whereas the pre-service posttest mean scores were higher. Does this suggest that something happens between the end of methods instruction and actual practice in the field to eradicate these gains?

In the administration of the Model Identification Test to children it had been noted that naive subjects often performed better than did instructed subjects. McIntyre (222) tested the hypothesis that the visual nature of the test elicits a set of perceptually biased responses from naive students, such biases having become inadvertently associated with correct responses to the test. He found many test items were subject to cueing and that these cues affected the lower grade students significantly more than students in the upper grades. The author suggested that if complexity and motion (the dominant forms of cueing) were used as distractors in preparing test items more powerful forms of the test might result.

Knisley _et al_. (170) developed an instrument to more reliably assess the effectiveness of a summer institute program for biology teachers. Prior to the 1973 institute, each of the participants was asked to assess the emphasis he or she placed on each of 57 topics during the previous academic year. This assessment was made again during the 1973-74 academic year. There was a significant increase in emphasis on all but two topics. Since the participants had also indicated on a post-institute rating form that they _desired_ an increased emphasis on these topics, it was hypothesized that the institute was effective in promoting this change.

Allen (7) investigated problems that handicapped readers were having with the 1968-69 ISCS test based on _Probing the Natural World_, Volume I. After revising the test, it was administered again. The study showed that reading comprehension was an important correlate to achievement on the test. In addition, it was found that an oral-demonstration technique was a valid method to compensate for lack of reading ability.

Robison (283) developed a group test that would measure the processes of controlling variables and interpreting data. Individual students were tested using the Individual AAAS Competency Measures. The results of these tests were used to develop a group test. Correlations between group items and individual measures was 0.70 for controlling variables and 0.66 for interpreting data. We would like to see more research on the validity and reliability of group tests on competency measures.

Also reviewed were studies by David (75), Doran and Guerin (86), Eastman (97), Maguire (202), and Solliday (321).

Physics

It seems that despite all efforts to stem the tide of declining enrollments in physics, the problem still remains. Educators have researched, debated, and otherwise focused on this issue. Perhaps it is then significant that the majority of "content-related" studies reported in this review are in the physics area, some of which deal directly with the issue of factors affecting enrollment and/or attitudes. In the 1973 review, all of the physics-related studies were placed in a single composite section to facilitate analysis. The same procedure will be followed in this review with the hope that eventually some clearer trends will begin to emerge.

We are able to report four studies that dealt directly with the factors which influence students' decisions regarding enrollment in physics. Laurence (178) found that 1) students' perceptions of whether their former science teachers were "warm accepting human beings" and 2) fear of failure due to perceived difficulty of physics were the two main factors influencing approach or avoidance behavior relative to physics enrollment. Interestingly enough, whether a student perceived his past science courses as being student-centered had no relationship to the enrollment patterns.

Using a path analysis technique, Bryant (47) examined data collected from 807 New York secondary public schools in an attempt to better understand the factors influencing physics enrollment. The final path model consisted of the variables: percentage of students from welfare families, amount spent per student for instruction, total school enrollment, number of students per teacher, dropout rate, percentage of students continuing in a four-year college, percentage of students enrolled in a traditional physics course and percentage of students taking physics prior to 12th grade. The college variable had the largest direct effect, while the welfare variable had the least direct effect. Perhaps additional efforts along these lines will yield more definitive data that can lend greater insight into the problem.

A study by Sprung (328) focused on factors influencing the decision _to_ enroll in physics and chemistry and factors influencing the decision _not_ to enroll. He found for the former category such factors as 1) importance to college plans, 2) planned college or science-related major, 3) importance to career goals, and 4) interest in science courses (this factor being stronger for physics than chemistry). Influencing the decision _not_ to enroll were such variables as 1) greater interest in other subjects, 2) lack of interest in physics or chemistry, 3) fear of

failure, and 4) lack of relevance to career goals. A sizeable percentage of non-enrollers in physics expressed the opinion that physics was probably too difficult. With a sample size of over 1700 students, these factors are likely quite valid and perhaps generalizable to the greater population of physics and chemistry students. If so, then we still seem to project an image that physics is a hard course, useful only insofar as it prepares one for college.

Dietrich and Pella (83) surveyed schools in Wisconsin and contrasted those with high physics enrollments with those with low enrollments. The authors indicated that few differences were found. However, they did find that schools with high physics enrollments had more students who planned to continue their education after high school, gave permission to take physics before grade 12, offered more than one type of physics course, and had larger total school enrollments.

In order to get a better picture of how recent trends in physics enrollments are being reflected in the national physics testing programs, Pfeiffenberger (261) analyzed the data from three such programs, the CEEB Physics Aptitude Test, the Advanced Placement Test, and the GRE Advanced Physics Test. The major findings were: 1) Since 1967-68 the number of candidates has dropped on the CEEB-PAT by 41 percent while the mean scores have risen about 3 percent. Boys continue to perform better than girls and the difference seems to be increasing slightly. The <u>number</u> of girls taking the examination has remained constant while the <u>percentage</u> has doubled. 2) In the Physics Advanced Placement Test, both the mean scores and numbers of examinees have risen slightly. 3) There has been a 33 percent decline in the number of examinees for the GRE Advanced Physics Test, whereas the mean scores have risen sharply. This latter result probably reflects the graduate enrollment trend. Less academically able students do not take the exam, thus inflating the mean score.

The status of physics teaching in Montana High Schools was studied by Dickison (82) to assess the progress made since 1959. He found that 1) high school physics was primarily for better students, 2) teaching objectives and textbooks were judged to be traditional, 3) science course improvement project courses were used mostly as supplementary materials, 4) the academic preparations of teachers had improved, and 5) laboratory facilities had improved only slightly.

Gardner (119) took a third look at the data which had been gathered in Australia for the purpose of detecting changes in the attitudes of students taking PSSC physics. Earlier articles were reviewed in 1973. The purpose of this third article was to shed some light on the earlier data, especially regarding discrepancies that occurred between the data of 1968-69 and of 1971. The latter data showed a significant decline in enjoyment of physics. It was suspected that since the later study contained non-continuers, these students were likely influencing the results. Additional data obtained by questionnaire allowed Gardner to regroup the data for more meaningful comparisons. When the students who elected not to continue physics were partialed out, there remained a significant, although smaller, decline in enjoyment of physics. Thus, there was concern that since the earlier assessment, even those who continued in physics had registered a decline on the enjoyment scale.

Tamir, Arzi and Zloto (337) administered an attitude scale to Israeli high school students in an attempt to identify variables affecting physics enrollments. It was found that not only did certain school variables, such as difficulty of the subject and attributes of the teacher, play an important role in the development of attitudes toward physics; social, economic, and political variables also operated significantly. Girls were found to reject significantly the perception that physics was a masculine subject. However, the attitudes toward physics and physicists by girls were generally less positive. It is extremely likely that many of the results reported in this study are culture-dependent considering the rather unique political situation in that country, for example.

We have been looking at attitudes toward physics and how they affect enrollment. Now we turn to studies that attempt to measure what happens to students who do enroll in the physics curriculum. Fletcher (111) reported a study to determine whether grade level was an important factor in achievement in physics. Two tests, the Project Physics Achievement Test and Algebra I of the Cooperative Math Test, were administered as pretests to 10th, 11th, and 12th grade students as well as to college freshman and sophomore physics students. The dependent variables were the Project Physics Unit Tests and pre-post Physics Achievement Test gains. No definite data resulted regarding whether students should take physics in grades ten, eleven, or twelve. It was noted, however, that for tenth grade students taking physics there was a significant drop in their overall science grade-point average upon completion of the physics course.

Surprisingly, there was only one study reporting the use of computers in the classroom. With the trend moving toward more computer use in physics instruction these kinds of studies will likely increase in number. In a study by Hughes (148), 51 high school students were formed into three treatment groups. One group performed experiments, collected and analyzed data in the traditional manner; a second group set up and performed the experiments but used computer simulations to obtain data for analysis; and a third group was given instruction sheets describing the experiments but analyzed computer-simulation data. Process skills measured were: 1) investigating relationships between variables as measured by a Data Manipulation Score, 2) reaching conclusions as measured by an Experimental Conclusion Score, and 3) interpolating, analyzing, applying, designing experiments, and reaching conclusions as measured by written Process Tests. The results were: 1) The computer-only group had the highest Data Manipulation Score, and 2) The Laboratory-Computer group had the highest Experimental Conclusion Score. With regard to the Process Test, Content Examination, and time spent in carrying out experiments, no differences were found.

Crooks (70) examined the variable of student learning in a large introductory college physics course for engineering majors. The independent variables were student evaluation of recitation instructor and instructor attributes and behavior. Also examined was grade prediction based on certain predictor variables. The latter showed that a mathematics pretest was the best predictor ($r = 0.60$) while such variables as physics pretest, selection index and most recent mathematics course added slightly to the variance (multiple $r = 0.68$). The results from the analysis of the relationship between instructor attributes and student evaluation suggested that the student-instructor personality interactions

played an insignificant role in determining the student rating of the instructor. The important variables appeared to be the more traditional ones, such as clarity and organization of presentation and ability to explain and answer questions. (Other studies dealing with instructor evaluation are found on p. 28.)

In a study reported by Holden (146), experimental textual material consisting of physics concepts written within a biological framework was given to one-half of a college physics class consisting of undergraduate life science students. The other half received the traditional materials. After approximately three weeks attitude and achievement measures were administered. Although no attitude differences were found, a greater achievement was attained by the group receiving the experimental materials.

A study by Theil (340) described the considerations involved in the design of a course in mathematical physics.

Chemistry

In the previous section we reported a study by Sprung (328) that shed some light on why students elect to enroll in chemistry and/or physics. This study was the only one that addressed itself to enrollment decision variables in chemistry. Perhaps chemistry is yet to face the problem of any significant reduction in numbers of enrollees.

Evans (101), in an attempt to find a method that would enable students to more effectively write chemical equations, developed a model for writing such equations. The model was based on behavioral objectives considered necessary for writing four types of chemical equations. These objectives related to skills judged to be necessary based on questionnaires completed by high school chemistry teachers. Three tests of ascending difficulty were given to students at the end of the teaching phase. One group received instruction on the use of the model whereas the other was given the traditional instruction. No differences resulted in the test scores of the two groups.

Wheeler and Kass (362) developed the Misconception Identification Test to require the student to predict the effect of changing certain variables on the equilibrium conditions of selected chemical systems. Six major misconceptions were investigated. The authors concluded that students operating at early or late concrete levels may benefit from a greater emphasis on a laboratory approach in which they can predict and observe the effect of varying certain variables on a chemical system at equilibrium.

Vickner (354) developed and field tested a Wheatstone bridge model for simulating Le Chatelier's Principle. The study indicated that both high school and junior college students perceived it as an aid in understanding the principle.

Also reviewed were studies by Minter (227), Batchellor (25), and Maybury et al. (214).

Biology

Feedback from teachers in the Israeli adaptation of the BSCS Yellow Version indicated that motivation was seriously reduced when the topics of study involved primarily plants as opposed to animals, according to a report by Tamir (338). Further testing with attitudinal instruments confirmed the general preference for the study of animals. However, there was consistently greater achievement in botany at all levels, except on the matriculation examinations where the achievement was the same. The author ruled out differences in difficulty (although we feel that the evidence was not very clear on this point) as the reason for these paradoxical results. No other explanations were offered for the puzzling negative correlations between attitude toward botany and achievement in that subject.

White (363) compared the hypothetical cognitive objectives with the operational cognitive objectives of two standardized tests in biology: The Nelson Biology Test (Form E, 1965) and the New York State Regents Exam in Biology (June, 1972). The sample consisted of tenth grade students from a Catholic high school in the New York area. Among other findings it was reported that the two tests were, in general, measuring different attributes on the operational level.

Also reviewed were studies by Gale (118), Martin (210) and Wilfong (367).

Education, Characteristics and Behaviors of Teachers

The number of studies devoted to research on teachers and their training, characteristics and behaviors has increased significantly in the past three years. Approximately 30 studies appeared in the literature of 1972, 60 in 1973, and 87 studies in the year 1974. Although many of the 1974 studies fell into clusters, a good number of these investigations possessed some overlap, e.g., the effects of microteaching on teacher questioning behavior and attitude.

Teacher Education

Several studies investigated the effects of various instructional methods of preservice elementary teachers' achievement of the science process skills, attitudes toward teaching science as a process, and teacher planning practice. For example, Widick (366) found that preservice teachers who received instructor directed exposure to the science process skills achieved significantly higher scores on the Process Instrument for Teachers of Science than did teachers who had to initiate their own process skill training under informal conditions. Instructor directed exposure to the skills could be in small, isolated increments or in an integrated fashion. However, when compared to the small, isolated increment group, the teachers who received process skill instruction in an integrated fashion had significantly higher scores in the application of these skills as measured by the Measurement of the Application of Scientific Methodology. In a similar study, Akey (4) found that preservice elementary teachers who had received process skill instruction via a lecture-discussion-laboratory

treatment showed greater posttest gain scores in science process skill achievement than subjects who received a lecture-discussion treatment or a laboratory treatment only.

The effects of basic science process skill instruction on preservice elementary teachers' attitudes, process skill acquisition and planning practices were investigated by Campbell (55). Seventy-six subjects were randomly assigned to one of two treatment groups. One group received instruction in the basic science process skills via self-instructional pamphlets. The other group did not receive this instruction. Results indicated that the experimental group had significantly greater achievement on the basic skills and designed more science process skill oriented lessons. Campbell also found that those teachers identified as being open-minded by the Rokeach Dogmatism Scale were more apt to plan process skill lessons than were closed-minded teachers. Analysis of scores obtained from an investigator-designed attitude instrument concerning the use of these basic process skills in the elementary classroom showed no significant differences between the two groups.

Gruber (129) also found that training elementary teachers in the basic science process skills affected their competency in these skills. When compared to a group of teachers not receiving process skill instruction (n = 24), Gruber found that the experimental group (n = 21) had significantly greater gain scores on a basic process skills test than did the control group. She also found that training in these skills resulted in a significant change in open-mindedness for the experimental group.

Jaus (155) conducted a study, similar to Campbell's, with 90 preservice elementary teachers, using instruction in the integrated science process skills as the manipulated variable. One group received integrated science process skill instruction through self-instructional pamphlets. A second group received the same instruction plus a three-page written communication which advocated the use of the integrated skills in the elementary classroom. A third group served as a control. Dependent measures included an investigator-designed integrated skills test, attitude measure, the Rokeach Dogmatism Scale, and teacher-designed science lesson plans. Analysis of variance revealed significant differences in favor of the two experimental groups on scores from the integrated skills test and on the number of integrated skill oriented science lesson plans designed by the subjects. No significant differences existed between the two experimental groups and the control group on the attitude measure scores. Nor were significant differences obtained on any of the dependent measures when the two experimental groups were compared. In contrast to Campbell's findings, Jaus did not find a relationship between a teacher's open-mindedness and the type of lesson plans written.

Piper (265) found that a televised inservice program used to train 66 teachers in Science - A Process Approach was effective in increasing process skill competency, developing attitudes toward teaching these skills, and teaching these skills in the classroom.

In another study concerning the science process skills, Berkland (30) compared the effects of two types of earth science courses on preservice teachers' understanding of the processes of science and their

attitudes toward science. The experimental group of 49 preservice teachers was taught an earth science course which allowed for and advocated individual investigations. The control group was composed of 154 non-science majors enrolled in a structured earth science course which did not allow for individual investigations. Results of the Wisconsin Inventory of Science Processes and the AAAS Process Measure for Teachers indicated that the experimental group had significantly higher scores on these measures than did the control group. Results from an attitude measure showed that the experimental group viewed science as "not difficult" and that science could be done without an extensive science background. The reverse was true for the control group.

In contrast to the previously mentioned findings, Pinkall (264) found that fifth and sixth grade teachers (n = 25) trained in ESS or process science workshops were not significantly different in knowledge of science processes, content or in attitudes about science or scientists when compared to a random sample of 25 teachers who did not participate in these workshops. The investigator, however, did find that the students of the workshop teachers scored higher in knowledge of the process skills, science content, and attitude toward science and scientists than did students of non-workshop teachers.

In an investigation involving 224 preservice teachers, Siemro (316) found that teachers who had taken science content courses where they designed and conducted their own investigations displayed significant favorable differences in attitude toward science as measured by the Beliefs About Science and Science Teaching than did teachers who had taken traditional science content courses.

These studies seem to indicate that effective programs can be developed to teach science process skills to elementary teachers, that this training is likely to influence the way that these teachers conduct their own science lessons, that participation in designing and carrying out investigations of their own (but perhaps with guidance from the instructor) is likely to be an important component of such programs, that knowledge of science content is not highly related to development of process skills, and that teachers who engage in activity centered programs have more favorable attitudes toward science.

Microteaching has been used for several years as a technique for developing skills deemed important for successful teaching. In general, it has been found that microteaching can be an effective tool for modifying teacher behavior. Student reactions to microteaching are generally favorable if it is conducted in a manner that is not too threatening but, as the following studies show, favorable attitudes do not always occur. Previous research has indicated that the amount and kind of feedback which the trainee receives is a potent influence on the effectiveness of the technique. Unfortunately, it has also been found that teachers who have developed skills through microteaching are not always judged to be more effective teachers than others who have not developed these skills. The following studies are consistent with these previous findings.

A semantic differential attitude scale was used by Sparks and McCallon (323) to measure the effect of microteaching with children on preservice elementary teachers' attitudes toward teaching science.

Twenty-six teachers enrolled in a science methods course carried out six science microteaching sessions with from two to five children during an eight week period. A control group enrolled in another science methods section did not have the microteaching experience. Comparison of pre- and posttest scores on the semantic differential showed greater gain by the control group. The authors concluded that too many microteaching encounters occurred during the eight week period, consequently affecting the experimental group's attitudes toward science teaching.

In another study of microteaching, Pisano (266) randomly assigned 30 preservice teachers to one of two microteaching groups to test the effects of supervising feedback on teacher behavior and attitudes. Both groups taught four 15-minute SCIS lessons to four randomly assigned second graders. Each lesson was audiotaped, but supervisory feedback was provided only to the experimental group. Analysis of covariance was used to test for differences in scores obtained from five dependent measures. Results indicated that feedback significantly increased the use of higher level inquiry skills, class participation, class interest, and lesson pacing of the experimental group. Significantly different scores were not obtained on the instruments which measured attitudes toward pupils, science or microteaching.

By analyzing a sample of secondary science student teachers' videotaped lessons, Mocadlo (230) also found that microteaching experiences in inquiry teaching produced significant differences in the inquiry level of the lesson when compared to student teachers who did not have the microteaching experience.

Microteaching was also used as the manipulated variable in a study of non-verbal teaching behaviors by Raymond (276). This investigator found that preservice junior high school teachers who had practiced microteaching with peers exhibited significantly more time in non-verbal teaching behaviors and interactions with pupils during student teaching than did a non-microteaching control group. Pupils of both groups of teachers did not, however, perceive either group as being more effective as teachers.

We seem to be much better at designing programs which modify teacher behavior than we are at showing that the modified behavior actually results in more learning by pupils. It is encouraging when we see research which goes that second mile. The effects of training preservice elementary teachers in sequencing objectives and designing programmed materials, and the subsequent achievement of fourth graders who used these programs were studied by Trojcak (348). She found that several stages of instruction in programming had a greater effect on developing the teacher's ability to design effective programmed instruction on friction than one or two stages of instruction. She also found that the fourth grader's achievement of the programmed instruction was directly related to the time spent on developing the teacher-constructed programs.

Atwood and Rogers (15) found that the cognitive style of preservice elementary teachers could be changed. Treatment consisted of carrying out <u>Science - A Process Approach</u>, SCIS, and ESS activities in a science methods course. Prior to treatment, 201 subjects were administered the Cognitive Preference Examination (CPE) and were given the same test after treatment. Analysis of the gain scores showed that significant differences

resulted on two factors of the CPE. The application cognitive preference increased significantly and the memory preference decreased significantly. Although mean score changes were small on these factors, the relatively high number of subjects used in the analysis resulted in significant differences.

Rhyne (279) analyzed pre- and posttest interaction analysis data of twelve college biology teaching assistants who were given ten hours of teaching methods instruction. Positive significant changes occurred in the subjects' indirect/direct teaching ratio, student/teacher talk ratio, non-verbal movement, time spent with individual students, and use of higher level questions. Although it is encouraging to know that we can produce these changes, we really need to know more about the effect of such teacher behaviors on pupil learning.

Shymansky et al. (313) investigated the effects of two teaching strategies on children's self-concept in science and their perceptions of the problem-solving process. One group of teachers was trained to teach elementary science in a student-structured way. Another teacher group was trained to teach science in a teacher-structured way. The subjects consisted of 250 first through fifth graders who were taught by one of the two strategies for a period of eight months. At the end of this period, data were obtained on two investigator-designed measures and analyzed by chi square analysis. Analysis of the children's scores on the self-concept in science instrument revealed no significant differences between the two methods of teaching. However, analysis of the perception instrument scores showed that the children who received the student-structured method perceived the problem-solving process as an active, independent process. On the other hand, children in the teacher-structured classes perceived the problem-solving process as being dependent on directions from an outside source. The implication of these findings is not entirely clear.

Okey (248) studied the effects of Bloom's mastery teaching strategy on teacher attitude and effectiveness. Okey trained eighteen K-8 inservice teachers to use a five-step mastery strategy. Five of these teachers split their classes, with one-half of the class being taught mathematics by the mastery strategy while the other half was taught the same subject matter by the traditional mode. Analysis of the children's achievement test scores showed that only one teacher produced significant differences in favor of the mastery strategy. Although the differences in mean scores for other classes were not significant, they consistently favored the mastery pupils. Scores from an investigator-designed attitude measure ($r = .58$) indicated that the mastery teachers were very much in favor of the mastery strategy. However, one cannot rule out the possibility that this favorable attitude was a reflection of the teachers' perception of what they were expected to like.

Ciesla (61) carried out a similarly designed study on mastery teaching using preservice elementary teachers. He also obtained significant positive attitude test scores toward the strategy from the mastery teachers. Ciesla did not find significant differences in pupil mathematics achievement test scores, however.

In view of some rather favorable reports on mastery learning in previous research and the almost wholesale acceptance of the philosophy on

which mastery learning is based, these ho-hum results are discouraging. Are our measurements so crude that the expected improvements go undetected or do we suffer from another case of oversell? One suspects that both factors are operating but perhaps the greater problem is that we have not yet engaged in the careful research and complete reporting that will enable us to tease out the conditions which are important for the successful implementation of a mastery learning strategy. Surely instructional systems are too complex to describe as "mastery" or "normative" and factors such as the extent to which students understand the intent of instruction and opportunities for and effectiveness of formative evaluation - factors that certainly exist to some extent in <u>any</u> instruction system - seem likely to be ones that determine the effectiveness of instruction.

Several studies were reviewed concerning the effects of competency-based or field-based teacher education models on teacher training. Lahnston <u>et al</u>. (173) compared the effects of a field-based and university-based preservice elementary teacher education program on children's cognitive growth in classification skills. Teachers from both programs taught classification skills to 202 children of varying grade levels. Analysis of covariance showed significant differences in classification skill which favored children taught by the field-based teacher.

Smigelski (319) compared the effects of a competency-based teacher education program and a non-competency-based program for secondary science teachers on developing humanistic behaviors. No significant differences were noted between the two training programs. Wineman (371), on the other hand, found that humanistic behaviors can be developed in a competency-based elementary science methods course when humanistic elements are included in the course.

Markle and Capie (206) developed and evaluated a competency-based physics program for elementary teachers and found that, besides an increase in physics knowledge and process skill competency, the teachers' attitudes toward physics and other science disciplines were greatly improved.

It is not clear what elements in these programs were responsible for the observed differences. Is it a clearer delineation of intent, a more pragmatic orientation to the program, more activities directly related to the act of teaching, more freedom on the part of pupils to decide how they will learn, or some other obscured variable that produces the result? We need to know.

In one of several studies concerning the impact of NSF institutes, Spradlin (327) collected data from 103 secondary science teachers prior to NSF institutes, after the institutes, and at the end of the following school year. Data were also collected from the students of the institute teachers. The investigator concluded that participation in the institutes altered teacher classroom activities toward more student-centered activities, increased the teachers professional images, and improved content knowledge. Spradlin (326) found no significant change in teacher perception of self or subject matter as measured by pre- and posttest scores of a semantic differential and the Annual Self-Inventory for Science Teachers. Dyche (96) obtained similar results from NSF institutes for biology teachers held at the University of Montana.

Lawlor (181) studied the effects of an NSF supported SCIS institute and the subsequent change in attitude toward science by the children taught by the NSF participants. Pupil attitude test scores and questionnaire responses indicated that the children taught by the SCIS trained teachers had significantly better attitudes toward science than did children taught science by non-SCIS teachers or by SCIS teachers who had not participated in the institute.

Macklem (201) studied the effects of a teachers' BSCS academic year inservice program on selected student learning outcomes. No significant differences on the BSCS final examination were obtained when student gain scores of the nine BSCS teachers were compared to students of nine non-BSCS teachers. Nor were there differences on scores obtained from the Wisconsin Inventory of Science Processes. There was, however, a significant difference in critical thinking in favor of the BSCS students as measured by the Watson-Glaser Critical Thinking Appraisal.

In the teacher education category, studies by Berger (29), Brewer (41), Cleland and Uffelman (62), Cross (71), Demchik (79), Deamer (90), Frosh (117), Hatcher (138), Jungwirth and Dreyfus (161), Litman (191), McCurdy (217), Napell (236), Nucholls (243), Schade (293), Sea (297), Villavicencio (355), and Whatley (361) were also reviewed.

Attitudes, Characteristics, Behavior

Many studies were reviewed concerning teacher and student attitudes, characteristics, and behavior. Quinn (271) found a positive correlation between a biology teachers' self-actualization and student attitudes toward biology. Self-actualization data were obtained from 30 teachers using the Personal Orientation Inventory. The Biology Interest and Attitude Inventory was used to collect attitudinal data from the 600 students of the teacher group. Results indicated that students of high self-actualizing teachers expressed significantly more favorable attitudes toward biology than did students of low self-actualizing teachers.

In a survey of 114 Pennsylvania elementary teachers, Shrigley and Johnson (312) found that the male teachers had a better attitude toward science than did female teachers. No significant differences in attitude toward science were found when age, grade level taught, school size or classroom organization were compared. Perhaps of greater importance was the finding that no difference in attitude toward science was found in relation to whether a teacher was using Science - A Process Approach, ESS, SCIS, or a science textbook approach.

Through analysis of two science teaching questionnaires returned by 309 educators in the State of Washington, Stronck (331) found many similarities and differences between K-12 teachers. They all desired to learn how to coordinate a K-12 sequence of science concepts and processes and wanted inservice programs to describe recent advances in science and their relevancy to students. All teachers rejected the memorization of facts as a goal of science. The elementary teachers differed from the secondary teachers in desiring ideas to create more exciting science activities, to manage curriculum materials, to individualize instruction, and to teach the science processes.

In a survey of 344 junior and senior high science teachers from 12 states, Lawrenz (182) found that senior high teachers rated themselves significantly higher than did the junior high teachers in areas such as effectiveness of lecture, knowledge of subject matter, career opportunities, and evaluating teaching effectiveness. The junior high teachers rated themselves higher than did the senior high teachers on use of audio-visual presentations. As in all surveys of this type, caution must be exercised in basing conclusions on self-ratings. Self-ratings are usually not objective and people tend to rate themselves higher than the actual conditions warrant.

Lawrenz (182) found that junior high science teachers made extensive use of audio-visual materials in their classrooms. This teaching technique, however, can be a drawback as pointed out by Markell (205). From data collected from students in 38 junior high science classes, Markell found that the use of filmstrips and films, among other techniques, rapidly lost favor with students.

In a survey of 100 North Carolina secondary science teachers and 100 non-science secondary teachers, Brock (43) found 1) the science teachers to be more realistic than were the non-science teachers, 2) male and female science teachers did not differ philosophically, 3) younger science teachers were more existentialist than were their older colleagues, and 4) science teachers who had taken a graduate level philosophy of education course were less pragmatic than were science teachers who had not taken such a course. Data were obtained using the Ames Philosophical Belief Inventory and the Science Educator Reaction Inventory.

In a survey of Michigan junior and senior high science teachers (n = 475), Faber (103) found that the junior high teachers viewed their professional preparation in science content and methodology as ~~much~~ less adequate than did secondary teachers. Although adjustments are being made to meet the needs of training preservice junior high science teachers, Faber contended that much more is necessary.

Using checklist data from 28 earth science teachers, Ogren (249, 250) found that those teachers who had adopted a recent New York State Regents earth science syllabus also tried many of the teaching procedures advocated in the syllabus. This finding is supportive evidence that teachers who adopted new science curricula under a voluntary basis are using the teaching procedures advocated by these curricula.

Support for the contention that adoption of new science curricula influences curricular-advocated teaching behaviors is brought out in a study by Simmons (317). In this study the teaching behaviors of randomly selected SCIS elementary teachers were analyzed using the Interaction Analysis of Science Teaching. A sample of randomly selected non-SCIS teachers were also analyzed with the same instrument. Results indicated that the SCIS teachers exhibited significantly more student-centered teaching behaviors than did the non-SCIS teachers.

A classic reversal of the adage, "What's good for the goose is good for the gander" was verified by Frantz (113) in a study of secondary school science teachers attending an astronomy institute. These teachers preferred teaching science by inquiry but preferred not to learn by this method.

Shrigley (311) obtained scores from 92 preservice elementary teachers on the Science from Concepts Achievement Test and correlated these with corresponding scores on the Science Attitude Scale for Preservice Elementary Teachers. Shrigley obtained a low Pearson product-moment correlation between these two measures (r = .25). The author concluded that a prospective teacher possessing high science content achievement does not necessarily have a more positive attitude toward science.

Butterworth (51) found that varying the number of verbal elements found in continuous discourse units and the distribution and frequency of occurance of such terms in the total communication ("linking" or kinetic structure) affected college students' attitudes about such lessons. Results showed that students who were presented biology lectures with greater "linking" (high kinetic structure) felt these lectures were better structured, easier to understand, more intellectually stimulating, and more helpful than were lectures with less "linking" (low kinetic structure).

Scott (296) studied the effects of planned classroom teacher verbal behavior and its subsequent effect on student verbal behavior and achievement in biology. Ten experimental teachers received instruction in the use, principles and rationale of the Verbal Reaction Behavior Log (VRBL). Based on the principles of the VRBL, the experimental group was taught specific biology subject matter with this unit of study. Ten control teachers were taught the same subject matter without the VRBL organized unit of study. Both groups of teachers taught the same unit of study and were monitored with audio-tapes for ten 30-minute sessions. Analysis of the tapes indicated that the experimental teachers and pupils verbalized a great deal more in the mid- and higher-order subcategories of the VRBL than did the control teachers and their students. Analysis of pupil achievement test scores for the unit of study also resulted in a significant difference in favor of the experimental students.

Eaton (98) investigated the effects of a 17 day SCIS inservice workshop on teacher questioning behavior, open- and closed-mindedness, perception of teacher behavior, and pupil performance in the science process skills. The experimental group consisted of 23 elementary teachers who participated in the workshop and taught SCIS. A control group consisted of 19 non-participants who taught science via a textbook approach. Post-treatment data were obtained from both groups on the Rokeach Dogmatism Scale, Reed's Teacher Competency Study, the Teacher Situation Reaction Test, the Fundamental Interpersonal Relation Orientation-Behavior, and audio-taped science activities (three per teacher). Significant findings showed the experimental group were more open-minded, wanted less control, and asked more high level questions. The pupils of the experimental teachers also showed significantly greater achievement in the science processes than did the pupils of the control teachers.

Shay (307) used the Science Classroom Inventory to investigate the relationship between a teacher's preference for student-centered, non-direct science instruction and several teacher characteristics. Data were obtained from 73 secondary science teachers and their 3812 students. Results indicated that a teacher's preference for student-centered, non-direct science teaching was positively and significantly correlated with the teacher being female, intuitive, and recognizing the choice of such a preference. It was also found that pupils enrolled in the student-

centered classes, indicated a greater interest in science courses than did pupils in non-student-centered courses.

Wright (373) found that biology teachers who carry out inquiry sessions in the classroom significantly reduce their amount of talk and have a corresponding increase of student talk when compared to non-inquiry sessions. The percentage of time spent verbalizing "data analysis and interpretation" and "procedures" was also significantly greater during the inquiry sessions than during the non-inquiry sessions.

In a unique study with 43 preservice elementary teachers enrolled in a science methods course, Lawlor (180) found that these teachers did not listen to each other when solving a common problem. Using one of Suchman's inquiry session problems, the preservice teachers asked questions of the instructor in order to obtain information to answer the problem. Lawlor tape-recorded the session and found that 70 percent of the questions asked by the preservice teachers did not use the information gleaned from previous questions. The author concluded that the subjects did not listen to one another.

Suchman has reported similar behavior on the part of students engaged in inquiry training sessions and has suggested that the frequent repetition of questions during such sessions is not due to inattention on the part of participants but rather, the participant is often unable to process information obtained from questions asked by others because he is at a different point in the problem solution. To him, the information is irrelevant. Later, when this participant progresses to the point that the information is relevant to his own solution of the problem, he repeats the same question. What appears to be inefficient learning resulting from inattention may not be inefficient at all. Indeed, even though our initial reaction to this research might be to encourage students to pay attention, it is quite possible that the real message is that we need to provide more opportunities for students to obtain answers to questions that are redundant.

In a descriptive study, Larson (177) analyzed the question-asking behaviors of 19 fifth grade science teachers and the responses of their students. Results showed that these teachers did not designate who should respond to a question over half the time, student responses followed a pattern that was teacher controlled, and 91 percent of the teachers' reactions to student responses were positive.

Smith (320) randomly assigned 62 preservice secondary science teachers to one of four treatments in a study of question-asking behavior. The treatment levels consisted of 1) reading articles on questioning (a placebo), 2) classifying questions, 3) planning high level questioning strategies, and 4) both classification and planning. Data from pre- and posttest peer microteaching sessions showed gains in the frequency of high level questions asked by all four groups. No significant differences in the frequency of high level questions were obtained between the four groups during the microteaching sessions. The author found, however, that cognitive style and philosophic-mindedness were positively correlated with the frequency of high level questions asked.

Medoff (223) conducted a descriptive study of 221 seventh grade students to determine the relation of pupil verbal interaction with student ability, self-image, and teacher questioning behavior in four subject areas. Results indicated that 1) teachers with high indirect/direct ratios asked significantly higher level questions and received more higher level responses than teachers with low I/D ratios, 2) English and social studies teachers asked more high level questions than did science and mathematics teachers, 3) student verbal participation in the four subject areas was not related to student reading ability, 4) there was no correlation between a student's verbal participation and his self-image, and 5) verbal participation by boys was two and one-half times greater than by girls in all subjects.

In the teacher attitude, characteristics and behavior category, studies by Arnfield (13), Beisenherz and Tucker (28), Boger (36), Brown (46), Cook (64), Jingozian (156), Leith (186), Martikean (209), Moglia (231), Muehlke (234), Penick et al. (259), Power and Tisher (267), Power (268), Prekeges (269), Self (298), Tamir (336), Tiangeo (343), Uffelman and Engel (349), Vargo (352), Wilson (369), Wright (374), and Zambotti and Fazio (378) were also reviewed.

Surveys

The majority of surveys are performed in order to obtain information of particular interest in a local situation. Consequently, few of them are of sufficient scope to interest a national audience and are not discussed in this review. Some, however, do report information of potential interest to a large group and these are discussed briefly in this section.

Ayers (16) surveyed the literature in science education published in 1970 and 1971 and found, not too surprisingly, that most authors are from colleges rather than from elementary and secondary schools. He also found few articles dealing with preschool, kindergarten, and the junior high areas. Since science is more firmly established in the higher levels of schools than in the lower and since major curriculum efforts in science began at these upper levels, this result is not too surprising. It does, however, suggest that science education in the lower grades has not been receiving the attention that it probably deserves. Perhaps the situation is improving. A number of studies reviewed in this document do deal with science education at the lower grade levels.

One of these was the survey of science teaching in elementary schools by Nelson (237). Nelson attempted to determine the kind of science instruction taking place in the New England, Mideast, and Southwest regions of the United States. Unfortunately, she received only a 30 percent response to her questionnaire, casting considerable doubt on the representativeness of the results. Based on the limited returns, it appears that the most prominent form of science materials used in elementary schools are single commercial texts or locally prepared materials. The science course improvement projects developed under NSF funding were used by 17-30 percent of the schools. The most frequent learning activity reported was lecture-discussion (50 percent or more respondents).

Whitla and Pinck (365) reported a very elaborate survey of the status of elementary school science in the state of Massachusetts. Two hundred forty-four school systems were surveyed with a 90 percent return. This represents 90 percent of the elementary schools in the state, 92 percent of the teacher population, and 96 percent of the student population. Consequently, the results should provide an accurate picture of school practice in Massachusetts. The focus of the survey was on the use of new curricula (SCIS, Science - A Process Approach, Minnemast and ESS). Results showed that in 48 percent of the schools one of the programs was used in some classes. It was estimated from the results that the programs were being used in about 20 percent of the classrooms, involving about 13 percent of the student population of the state. Of those school systems using one of the new programs, about 13 percent were strongly committed to the NSF programs, 5 percent were committed but not strongly, and 29 percent use the programs but were not committed to their use. The most popular program in use in Massachusetts was ESS, followed by SCIS, SAPA, and Minnemast. In addition to data on the use of the new curricula, the survey obtained information related to attitudes of teachers and administrators toward the new programs and assessed the factors that seemed to influence implementation. Some of the differences between systems committed to the NSF curricula and those using textbook programs are shown in the following table.

TABLE II

Differences Between School Systems Using NSF Curricula and Those Using Textbook Programs

	NSF System	Non-NSF System
System provides workshops in science for teachers	73%	23%
System provides workshops in science for principals	20	9
System has a person responsible for elementary science who spends more than 25% of time on coordination	40	9
System has designated K-6 or K-12 science coordinator who spends more than 25% of time on coordination	33	5
System has some specialized science teachers	31	19
Common teaching approach in the system is a classroom teacher with no help from an elementary science specialist	51	94
System performs many coordination activities at the central office level rather than building level	38	14
System's policy provides a relatively high degree of support for released time for workshops and visits, and credit and remuneration for workshop attendance	38	23

At the college level, Kormondy, Kastrinos and Sanders (171) surveyed 100 colleges to determine what biology courses were offered. Of the 68 responses, 54 reported offering more than one freshman course while 14 offered only one. The report indicated the type of courses offered, enrollments and the style of presentation. In another survey dealing with college biology, Jacobs (153) surveyed 500 biologists (210 replied) to determine what skills they considered important for teaching college biology and whether they had acquired those skills as a graduate student. Many of the qualities considered important for teaching were not acquired in graduate study.

In an effort to determine high school students' perceptions of science teachers and science classes, Cooper and Petrosky (65) had high school students write essays on their "best class" and "worst class." The essays were then broken into T-units and categorized. Sixty-eight percent of the T-units concerned the teachers' personal style and unique manner of teaching, with 29 percent dealing with personal traits alone. Evidently the personality of the teacher was an important influence on the student's attitude toward the class.

Exline (102) surveyed earth science education in Virginia. Most of his data are of only local interest, but his finding that only about 18 percent of earth science teachers in the state were endorsed to teach earth science may be indicative of a national shortage of earth science teachers. It is consistent with Retherford's finding that only 13 percent of the teachers using Time, Space and Matter were earth science majors. (See p. 25).

In view of the present concern over the low number of women in science and science related occupations, a survey of career development of gifted students in science conducted by Hansen and Neujahr (137) is of some interest. Data were collected from students enrolled in a science honors program at Columbia University during 1959-1961 and again in 1971-1972. It was found that, in high school, males and females were virtually identical in mean IQ and in their intention to pursue science as a career. However, males consistently scored higher on mathematics and science standardized tests and pursued science as a hobby outside of the classroom more frequently than did females. Females electing science careers tended to select biology. These differences persisted throughout graduate school. In spite of the attention given to providing opportunities for women in science, the same percentage of women were enrolled in the science honors program in 1971-1972 as were enrolled ten years earlier. In addition, the pattern of scores on the standardized tests as well as career selection patterns remain virtually unchanged. It seems likely that the observed differences between males and females on standardized test scores and the greater frequency of science related hobbies among males are related to the disparity of males and females who seek science careers. It might also be noted that females frequently do poorer on Piaget tests of formal operational thought than do males of the same age. This too, is likely to be related to the lower frequency of women in science related fields. What we need to know now is why these differences exist. Are they due to cultural influences on role identification, differences in treatment (including counseling) of males and females in the public schools, or even the seldom discussed possibility that evolutionary influences have resulted in males being better equipped biologically for work in science?

Other surveys which were reviewed are Baldwin (17), Blomberg (33), Boekenkamp (34), Brooks (44), Cash (58), Curtis (73), Donaldson (85), Drake (89), Fazio (105), Fifer (108), Fisher and Fraser (109), Hutchinson (151), Karla (163), Knight (169), Krause (172), Langford (175), Law (179), Mack (200), McCoy (215), Newport (238), Ogden (246, 247), Phillips (263), Prinzing (270), Rosier (285), Rosier and Williams (286), Selser and Milliken (299), Shomali (310), Spencer (324), Stronck (332), Supinski and Szabo (333), Welling (360), Williams (368), Young (377), Ziarko (380), and Zimmerman (381).

Miscellaneous

Despite all efforts to classify reports which were reviewed, some do not seem to fit into our scheme and are reviewed here.

In the 1973 Summary of Research in Science Education, Rowe and DeTure reviewed a book by Comber and Keeves, Science Education in Nineteen Countries: International Studies in Evaluation I. A summary of much of that information is found in the article by Keeves (164). Rosier (284) has also summarized information on science achievement among the various Australian states.

Jordan (159) compared, using a test of science misconceptions, the performance of males and females who attended integrated and segregated schools. Although the abstract does not state this, the population studied appears to be all black. Jordan found that females in integrated schools had more science misconceptions than did males in integrated schools. Also females in integrated schools had more science misconceptions than did females in segregated schools. However, no differences were found in the number of misconceptions held by males in integrated and in segregated schools.

Loose (194) has described some statistical procedures for studies involving aptitude-treatment interaction (ATI). Of some interest are his procedures for using standard deviations and correlations between criterion and aptitude scores to determine whether analysis of covariance or ATI analyses are called for.

In another study dealing with methodology, Herron, Luce and Neie (142) discussed the problems associated with using the individual or the class as the experimental unit in analyses of variance. Their data suggest that conclusions are likely to be similar regardless of whether the proper or improper choice of experimental unit is made.

After sampling magazine and news articles in seven Arab countries, Haddad (132) concluded that the Arabic press of the Middle East gives little attention to the interaction between science and society.

Other studies reviewed in this category are Crumb (72), Drew (91), Ficklin (106), Guard (130), Hanavan (135), Johnson (157), McDonald (218), Quinn (272), Zoller (382), and Zunde (383, 384, 385).

Implications of the Research Reviewed

When one attempts to review research or when one reads a review of that research, despair hovers like a cloud. One study seems to support a given practice, the next seems to contradict the first, and the following ten report no significant difference. Where we would like to see unambiguous answers we find suggestions which beg for thoughtful interpretation. And we find new questions. This is the nature of research, whether it is in the "hard" sciences or in the less certain realm of human study. We cannot afford to ignore the limited information we have simply because it doesn't lead to certain conclusions. Neither can we afford to assume that the interpretations that we make are so sure that further investigation is unwarranted. It is within this frame of reference that we attempt to summarize implications of the research that we have reviewed.

Expository vs. Discovery Learning

One of the controversies in science education over the past decade has been over the relative importance of expository and discovery learning. Weimer (338) did a critical analysis of studies that compare discovery oriented and expository instruction in the fields of mathematics, science, language, geography, and vocational education. The studies analyzed focused on retention or transfer. The author reported that no clear evidence of a single superior method of teaching was indicated. It is, perhaps, a measure of our naivete that so many researchers seem to expect some such clear indication that "method A" is superior to "method B." An instructional system is complex and most of the variables extant in the system have been shown to affect learning under some set of conditions. We know, for example, that the personalities of both teacher and student influence learning, that the difficulty of the learning materials may interact with method of instruction, that reading level or the kind and amount of laboratory activity can influence learning, and on and on. What we do not know--and what researchers so often fail to tell us--is the set of conditions under which each of these variables will or will not have an influence. Some hint of the conditions under which discovery learning may be better or worse than expository learning is found in the study by Danner (74). In his analysis it was found that the expository method of instruction was more effective when a difficult lesson on pressure was being taught. Conversely, the discovery approach was more effective when the easier pendulum lesson was taught. It seems reasonable to assume that expository presentations are better when the material to be taught is so difficult that students are unlikely to discover important relationships on their own while discovery approaches are preferable when such relationships are more transparent.

When it is possible for students to discover that which we want them to learn, the increased interest and motivation that generally result from discovery approaches will increase the attending behavior of the student; therefore, more is learned. However, the increased attention of the student has little beneficial effect if the student is unable to sort the important observations from the misleading. Indeed, a more structured, expository presentation may be desirable to prevent the student from being distracted by observations which are irrelevant or misleading when the

lesson deals with a difficult concept. As teachers, we must shun the simplistic position of thinking that discovery learning is always good or bad. Rather, we must think about what we want to teach and use our professional judgment to decide whether it is reasonable to expect students to discover the concepts and principles that we hope to teach under the conditions of the discovery lesson. If this does seem reasonable, we should capitalize on the increased interest of discovery approaches to present the lesson, But, when this does not seem reasonable, we should unapologetically structure the lesson in an expository fashion to enhance the probability that students will understand the idea we hope to teach.

Learning and Manipulation

Closely related to the question concerning discovery learning is one concerning the importance of having students manipulate physical materials in their lessons. Certainly the developmental psychology of Piaget would argue that physical manipulation of concrete objects may be important in learning, particularly for younger students. Even for individuals who have advanced to the stage of formal operational thought, concrete experiences are likely to be important when the learner is operating in a new area. However, research indicates that physical manipulation is important in some instances whereas in other instances it appears to make no difference.

The ambiguous results are likely to be due to two considerations. One is the level of intellectual development of the child; the other is the attending behavior of the learner. These factors are seen in the results of two studies; one by Macbeth (199) and the other by Halsted (387) which was reviewed by Rowe and DeTure in the 1973 Summary of Research. Macbeth found that kindergarten children learned more from science lessons when they were given an opportunity to manipulate apparatus than when they were simply allowed to observe, but this result was not repeated with third grade children. It is tempting to conclude that the active manipulation of materials is important for very young children but not for older ones and attribute this to the increased intellectual development of the older learner. This may be true, but the age at which the manipulation ceases to be important is likely to depend on the kind of learning activity. Halsted, working with older students in a high school chemistry class, found that students appeared to learn more when they were actively involved in making models of chemical compounds. In both studies, those who did not manipulate the materials did watch others do the manipulation. One could argue that all subjects had benefit of concrete experience appropriate to their level of intellectual development.

Perhaps the important variable in both cases is simply the attending behavior of the students and not the level of intellectual development. Kindergarten children are likely to have a very short attention span. If they are not actually manipulating the equipment, they may be distracted from even the most interesting experiments. By the time children are in third grade, they have learned to watch and listen to others and may learn just about as well when others do the manipulations, provided that the activity is sufficiently interesting to capture their attention. The results of the Halsted experiment may be explained in a similar fashion.

Watching someone else build a molecular model is not inherently interesting. Students could easily fail to see the importance of the activity and let their minds wander. Not so if they must do the work themselves.

Then two factors are likely to be important when one considers the manipulation of physical materials. The first is whether at the student's level of intellectual development, he is likely to benefit from concrete experience. If so, that experience can be provided through actual manipulation of materials or through some kind of demonstration or visual simulation. Which procedure is selected will then depend on the likelihood that the student will attend to the salient features of the experience. If the experiment is inherently dull but still instructive, it would perhaps be best to ask the student to do the manipulation himself in order to increase his attention. If, however, the experiment is inherently interesting but complex, it might be best to have someone else do the manipulation while the student watches and listens as the teacher focuses on the important features of the activity.

Piaget

The implications of Piaget's work have been mentioned in the discussion of discovery learning and manipulation of materials. It is little wonder that science educators have shown considerable interest in his work. We only wish that they understood it better. Research based on Piaget's theory has not always been good. Many ill-conceived studies are performed simply because the author does not understand the theory as well as he might. There are other problems, too. The methodology used by Piaget is quite different from the standard research methodology taught in college. Since the techniques are less familiar, researchers are more likely to commit simple methodological errors which lead to questionable interpretations. Phillips (262) describes some of the common errors in his paper. It is certainly worthwhile reading for anyone who plans to conduct studies related to Piaget's model.

It is discouraging that so many people still seem to be trying to speed up the intellectual development of children through some kind of short-term experience. All of the research to date indicates that one will not change a non-conserver into a conserver or a concrete operational student into a formal operational student by having the student go through a few training sessions. If the training sessions are very closely related to a specific test, the results on that specific test may change but the student will still demonstrate his prior level of intellectual development on a different test.

This is not to say that we should not include activities designed to enhance intellectual development or that such efforts will be ineffective. The work that Karplus and his associates have done in the development of SCIS suggests that activities which are carefully planned to enhance intellectual development can have an effect <u>over a long period of time</u>. The intellectual development that we are talking about is complex and is not subject to dramatic change as a result of short term experience.

One of the problems related to Piaget's work is being able to assess the level of intellectual development of students. This is of particular interest in high school courses such as chemistry, physics, and mathematics where a large proportion of the course content seems to presuppose that students operate at the formal operational level. We need to know if our students have developed to this level and, if they have not, adjust our instruction accordingly. Herein lies the problem. How do we find out? It really is not practical to give individual tests to entering students, and there is considerable question concerning the validity of written tests that have been developed. Raven's Test of Logical Operations has been shown to account for a substantial portion of the variance in a test of science content comprehension (Raven and Polanski, 275) and to correlate highly with achievement of black college students in physical science and biology (Raven, Hannah and Doran, 274). However, the same can be said about normal standardized tests of aptitude such as the SAT. It is not clear at this time whether written tests such as the one developed by Raven are more useful for identification of students who are not operating at the formal operational level than are older tests designed for other purposes.

Work related to Piaget's theory raises some questions that are likely to be politically sensitive. Do blacks and females demonstrate a lower level of intellectual development than whites and males respectively? The answer depends on the context in which the question is asked. In Griffiths' (128) study of college students, he found no difference in Piagetian level observed across racial groups. But college students are a select group and selection factors may obscure differences that might be observed in a random sample of individuals from different racial groups.

Nordland, Lawson, and Kahle (241) tested students in "disadvantaged" schools which had substantial numbers of blacks and Spanish-Americans and found that acquisition of conservation concepts lagged behind expectation in these racial groups. Rowe and DeTure also cite a study by Johnson (388) which showed that low socio-economic status students did not perform as well on classification tasks as did their richer counterparts. In addition, there have been numerous cross cultural studies which indicate that the level of intellectual development at a given age differs from one culture to another. There is nothing in any of these studies to indicate that the observed differences are due to genetic factors rather than environmental ones, but the evidence strongly suggests that differences do exist. We need to be aware of these differences, we need to seek the causes of these differences, and so far as it is humanly possible, we need to overcome these differences.

In the studies reviewed in this summary, not much is said about the relative intellectual development of males and females. However, other studies suggest that females lag behind males in the development of formal operational thought. This could easily account for the limited number of females who seek careers in science. Once again, we do not know the extent to which these differences are due to genetic or to environmental factors but we need to be aware of these differences and see what can be done about them.

Objectives, Organizers, Mastery Learning, and Individualized Instruction

Behavioral objectives and mastery learning have been the rage in education during recent years. Still, the research in these areas has been less than definitive. At times giving objectives to students seems to help but at other times it doesn't. It seems likely that it all boils down to a question of whether or not the student knows what is expected of him. If the teacher makes a point of informing the student about what is expected through verbal statements in class, frequent short quizzes, discussion of previous exams used in the course, or through tightly structured instructional materials, lists of behavioral objectives are likely to provide redundant information and have little effect on student performance. However, if other devices are not used to inform the student about the expectations in the course, the objectives (if clearly written) can be quite helpful. The same thing probably can be said about advance organizers. To the extent that an advance organizer provides information to the student concerning what is to be abstracted from a learning activity, the organizer may be effective. But if the student already has in his head an organizational framework which serves the same purpose or if the student is provided with other means of obtaining an organizational framework, the organizer is likely to be redundant and of little value.

The research on mastery learning and individualized instruction is closely related to the research on behavioral objectives. The three ideas usually appear together. And, like the research on behavioral objectives, the research in these two areas does not provide consistent results. Jim Okey's (248) study of mastery learning appears to be typical. Of the five teachers in his study who taught mathematics to students using a mastery learning strategy, only one produced greater gains among the students using the mastery learning strategy. In no case did students suffer from this approach, but it didn't always seem to help. We may reasonably ask, "Why?" The answer may lie in how students react to the increased responsibility that normally accompanies mastery or individualized strategies. Some students are confused and frustrated by freedom of choice and do not achieve very much as a result (Humphreys and Townsend, 149). Furthermore, students may not be as capable of planning a sequence of instructional activities as is an experienced teacher (Gunter, 131). In addition, less able students are either not able to properly interpret the feedback that they receive concerning their performance or lack the motivation needed to do additional work in the face of unfavorable feedback. At least we know that high ability students in an individualized program spend <u>more</u> time working on instructional materials than do less able students and we know that students at the bottom of an ISCS class are more willing to skip instructional activities than students at the top of the class (McCurdy, 216). Findings such as these and the well documented fact that students in an individualized program tend to procrastinate suggest that we need to provide some safeguards if we expect students to achieve in individualized programs. Students are helped when the units of study are kept short, when feedback is frequent, and when progress is carefully monitored. For some students, it is probably necessary for the teacher to provide considerable guidance in structuring the learning activities as well.

Teacher Education

With the increased interest in science processes among science educators, it comes as no surprise that science process training has received considerable attention in recent research on teacher education. These studies seem to indicate that effective programs can be developed to teach science process skills to elementary teachers, that this training is likely to influence the way that these teachers conduct their own science lessons, that participation in designing and carrying out investigations on their own (but perhaps with guidance from the instructor) is likely to be an important component of such programs, that knowledge of science content is not highly related to development of process skills and that teachers who engage in activity centered programs have more favorable attitudes toward science.

Microteaching has been used for several years as a technique for developing skills deemed important for successful teaching. In general, it has been found that microteaching can be an effective tool for modifying teacher behavior. Student reactions to microteaching are generally favorable if it is conducted in a manner that is not too threatening, but favorable attitudes do not always occur. Previous research has indicated that the amount and kind of feedback which the trainee receives is a potent influence on the effectiveness of the technique and, unfortunately, it has been found that teachers who have developed skills through microteaching are not always judged to be more effective teachers than are others who have not developed these skills. In general it is found that we can develop teacher education programs which result in teachers being able to demonstrate the competencies that we are trying to teach, but we often fail to find that these increased competencies result in greater achievement on the part of pupils of the teachers we have trained. Either the competencies that we are teaching are not the right ones, the teachers that we train ignore what they have learned when they get into their own classrooms, or the effect of these competencies is diluted in the complexity of the classroom to the point that no effect can be observed. We have a long way to go in learning how to teach teachers.

It is perhaps ironic that at a time when NSF efforts in teacher training seem to have come to an end, we begin to see evidence that these efforts have had a beneficial effect. Spradlin (327) reports that participation in an NSF institute altered teacher classroom activities toward more student-centered activities, increased the teachers' professional images, and improved content knowledge. In another study, Lawlor (181) found that children taught by teachers who had attended an NSF institute on SCIS had better attitudes toward science than did children taught by non-SCIS teachers or by SCIS teachers who had not participated in the institute. Although such favorable results are by no means universal, these studies do not represent isolated events.

Surveys

We tend to turn up our noses at surveys and descriptive research in general but decisions still must be made and our data base is often appallingly small, biased, or both. As a case in point, much attention

has been given in recent years to the declining enrollments in physics. Does such a trend exist? These reviewers have seen no data on a national sample to indicate that such is the case. There are data that suggest a problem exists but the data are either local in nature or competing explanations exist. Are some individuals reacting to local change and others simply spreading the rumor or is the problem real? Another example surfaced when a member of the Purdue faculty recently reported the results of a survey which seemed to indicate that the course content improvement project materials developed under NSF funding are being used in a small fraction of the public schools. A Massachusetts audience refused to believe the report. Were their biases due to the substantial use of these materials in their own state (c.f. Whitla and Pinck (365) discussed on p. 51) or were the data reported incorrect? Data of this sort do affect our policy decisions. It is important that we have accurate information.

These summary comments in no way cover all of the research reviewed in this paper. They do, however, summarize much of what we know concerning several important issues. It is our hope that they will provide direction for both classroom practice and future research.

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